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RESEARCH MEMORANDUM

INVESTIGATION OF THE NACA 4-(4)(06)-057-45A AND NACA 4-(4)(06)-057-45B TWO-BLADE SWEPT PROPELLERS AT FORWARD MACH NUMBERS TO 0.925

By James B. Delano and Daniel E. Harrison

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Langley Air Force Base, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

Investigations of the NACA 4-(4)(06)-057-45A and NACA 4-(4)(06)-057-45B two-blade swept propellers have been made in the Langley 8-foot high-speed tunnel at blade angles of 25°, 55°, 60°, 65°, and 70°. The maximum forward Mach number reached in these investigations was 0.925.

Comparison of results for the swept propellers with those previously reported for the NACA 4-(4)(06)-04 two-blade straight propeller showed that the use of large amounts of sweep provided only moderate delays in the onset of adverse compressibility effects and that the measured delay was only 25 percent of that predicted by the use of simple infinite-span sweep theory. The swept propellers were 10 percent more efficient than the straight propeller at a forward Mach number of 0.85 for the design blade angle of 60°.

INTRODUCTION

The NACA is conducting a general investigation to study the effects of compressibility, design camber, blade sweep, thickness ratio, and dual rotation on propeller performance at transonic speeds. Results of the first two phases of this investigation dealing with the effects of compressibility and design camber were presented in references 1 and 2. The first part of the investigation dealing with the effects of blade sweep was presented in reference 3 for the propeller with straight blades. This propeller has the same basic blade characteristics as the swept propellers to permit evaluation of the effects of large amounts of blade sweep on propeller performance.

Investigations of model swept propellers, references 4 and 5, have shown beneficial effects of sweep from tests at very low advance ratio and high tip speed. Flight investigations, reference 6, and wind-tunnel investigations, reference 7, of the same full-scale swept and unswept propellers, have shown no significant differences in the performance of swept and unswept propellers. The small differences between the efficiencies of the swept and unswept propellers may be due to the small amounts of sweep employed in the outboard sections (15° at the 0.7-radius station and increasing gradually to 45° at the tip). In addition, the test results, reference 7, indicate that the tip Mach numbers may not have been sufficiently high to encompass the speeds for which sweepback may have been beneficial. A preliminary investigation, reference 8, to determine the effect on propeller performance produced by sweeping back only the tip sections produced encouraging results. The onset of adverse compressibility effects was delayed approximately 0.12 in tip Mach number and the maximum efficiency was increased about 2 percent at supercritical tip Mach numbers compared to the results for a similar unswept propeller.

On the basis of the results of reference 8 it was believed that larger delays in the onset of adverse compressibility effects and high efficiencies at supercritical speeds could be obtained by employing large amounts of sweep all along the propeller blades. Consequently, two propellers were designed having the maximum amount of blade sweep permitted by consideration of blade stresses alone. An investigation of these swept propellers was made up to a forward Mach number of 0.925 in the Langley 8-foot high-speed tunnel.

Force-test data and a limited analysis of the results of the investigation of two NACA swept propellers are presented at this time to expedite publication of this information. Large-scale plots of the basic propeller characteristics, figures 6 and 7, are available on request to the NACA.

SYMBOLS

b blade width, feet

c_{l_d} blade-section design lift coefficient

C_P power coefficient $\left(P/\rho n^3 D^5\right)$

C_T thrust coefficient $\left(T/\rho n^2 D^4\right)$

D	propeller diameter, feet
b/D	blade-width ratio
h	maximum thickness of blade section, feet
h/b	blade thickness ratio
J	advance ratio $\left(V_o/nD\right)$
M	tunnel-datum (forward) Mach number (tunnel Mach number uncorrected for tunnel-wall constraint)
M_t	helical-tip Mach number $\left(M\sqrt{1 + \frac{\pi^2}{J^2}}\right)$
$M_{x_{cr}}$	theoretical section critical Mach number
n	propeller rotational speed, revolutions per second
P	power, foot-pounds per second
q	dynamic pressure, pounds per square foot, $\left(\rho V^2/2\right)$
R	propeller tip radius, feet
r	blade-section radius, feet
T	thrust, pounds
T_c	thrust disk-loading coefficient $\left(T/2qD^2\right)$
V	tunnel-datum velocity (tunnel velocity uncorrected for tunnel-wall constraint), feet per second
V_o	equivalent free-air velocity (tunnel-datum velocity corrected for tunnel-wall constraint), feet per second
x	blade-section station (r/R)
β	section blade angle, degrees
$\beta_{0.7R}$	section blade angle at 0.7-tip radius, degrees

η efficiency $\left(\frac{C_T}{C_P} J\right)$

η_{max} maximum efficiency

Λ section sweep angle, degrees (the angle formed by the intersection of the section radius, which is perpendicular to the chord line of the section at its midpoint, with a line passing through the locus of midpoints of the chord lines of the sections. The angle is measured in the plane defined by the section radius and the section chord line for the design condition, see fig. 4.)

ρ air density, slugs per cubic foot

APPARATUS AND METHODS

The apparatus and methods described in reference 1 were used in this investigation which was conducted in the Langley 8-foot high-speed tunnel. A sketch of the 800-horsepower dynamometer installed in the tunnel is shown in figure 1.

Propellers.- Three two-blade propellers 4 feet in diameter were used in this investigation. Photographs of the blades are shown in figure 2 and the blade-form curves are given in figure 3. All blades were designed having the same blade loading to produce minimum induced energy losses (profile drag assumed equal to zero) at a blade angle of 60° at the 0.7-radius station and at an advance ratio of 3.65. One propeller has straight blades and is the NACA 4-(4)(06)-04 propeller (the results of this investigation are presented in reference 3). Two propellers have swept blades employing large amounts of sweepforward and sweepback and are designated the NACA 4-(4)(06)-057-45A and NACA 4-(4)(06)-057-45B propellers. The last group of letters was added to the conventional propeller designation used for straight blades to show the amount of sweep (45° of sweepback) at the 0.7-radius station. The swept blades differ only in pitch distribution, and the letters A and B are used to identify each blade. The pitch for swept blade B is washed out approximately 2° at the root and tip sections (the pitch for blade B is 1° lower at the root and tip sections and 1° higher at the "knee" sections than for the corresponding sections for swept blade A). All propellers have the same distribution of NACA 16-series sections along the blade. The section blade widths of the swept blades are larger than those of the straight blade by a factor approximately equal to the reciprocal of the cosine of the section sweep angle. This was done to obtain the same thrust loading as for the straight blade.

Figure 4 illustrates the orientation of the blade sections with the section velocity vectors and the way in which the sweep angle is measured. The blade section at radius r is installed at right angles to the radius passing through the chord midpoint so that, neglecting induced effects, the section is in line with the relative resultant section velocity. The plane of the blade section coincides with the plane formed by the velocity vectors. The local sweep angle is measured in the plane formed by the chord and the radius passing through the chord midpoint. It is the angle formed by the radius through the chord midpoint and the projection of the locus of the chord midpoints on the plane formed by the chord and radius through the chord midpoint.

TESTS

Thrust, torque, and rotational speed were measured through a range of blade angle, advance ratio, and forward Mach number. For each tunnel Mach number the propeller was run at a constant blade angle (measured at the 0.7-radius station) and the rotational speed was varied. The range of blade angles covered for each forward Mach number is given in the following tables for the swept propellers only:

NACA 4-(4)(06)-04-45A propeller blade angle at 0.7-radius station $\beta_{0.7R}$ (deg) at forward Mach number M -									
0.23	0.53	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.925
25	55 60 65		55 60 65	55 60 65 70	55 60 65	55 60 65 70	60 65 70	60 65	65

NACA 4-(4)(06)-04-45B propeller blade angle at 0.7-radius station $\beta_{0.7R}$ (deg) at forward Mach number M -								
0.53	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.925
55 60 65	65	55 60 65	55 60 65	55 60 65	60 65	60 65	65	65

REDUCTION OF DATA

Propeller thrust.- Propeller thrust as used herein is defined as the shaft tension produced by the spinner-to-tip portion of the blades. The method used in determining thrust tares and in evaluating the propeller thrust is described in detail in reference 1.

Propeller torque.- Torque tare corrections were found to be small and dependent only on rotational speed. Spinner-tare corrections were made to the indicated torque readings (maximum correction of 1.2 foot-pounds at 6000 rpm).

Effect of diameter.- The diameter of the swept propellers decreased as the blade angle was increased because of the large amount of sweep incorporated in the blades. The nominal diameter is 4 feet at the design blade angle of 60° and the greatest change in diameter was 4.3 percent of the design diameter. All propeller characteristics are based on the actual propeller diameter which was measured for each blade angle.

Tunnel-wall correction.- The force-test data have been corrected for the effect of tunnel-wall constraint on velocity at the propeller test plane using the method described in reference 1. The results are presented in figure 5 as the ratio of free-air velocity to the tunnel-datum velocity as a function of thrust disk-loading coefficient and the tunnel-datum Mach number.

Accuracy of results.- Analysis of the accuracy of the separate measurements required to define completely the propeller characteristics has indicated that errors in the results presented herein are probably less than 1 percent.

RESULTS AND DISCUSSION

The basic propeller characteristics are presented in figures 6 and 7. For each value of tunnel-datum Mach number M the propeller thrust and power coefficients and efficiency are plotted against advance ratio. The variation of tip Mach number with advance ratio is also included. As used in this report, the tunnel-datum Mach number M is not corrected for tunnel-wall constraint. However, the free-air Mach number can be obtained by applying the tunnel-wall corrections, presented in figure 5, to the tunnel-datum Mach number. At the high Mach numbers the tunnel-wall correction is generally less than 1 percent but, in the exact use of the basic propeller characteristics presented in figures 6 and 7 wherever small changes in Mach number produce large changes in propeller characteristics, the tunnel-datum Mach number should be corrected to free-air Mach number.

<u>Effect of forward Mach number and blade sweep on maximum efficiency</u>.- The variation of maximum efficiency with forward Mach number is presented in figure 8 for all the blade angles investigated. Similar results, reference 3, for the NACA 4-(4)(06)-04 straight propeller are shown for comparison. Differences in maximum efficiency for swept propellers A and B were in general insignificant and within the experimental accuracy. Generally the efficiencies for propellers A and B are 1 to 2 percent lower than for the straight propeller at subcritical forward Mach numbers. At supercritical forward Mach numbers, sweep increases the efficiency and reduces the rate of efficiency loss with forward Mach number. For the design blade angle of 60° and a forward Mach number of 0.85, the efficiencies for the swept propellers were 10 percent higher than those for the unswept propeller.

Sweep produced only moderate gains in the critical forward Mach number, approximately 8 percent. For the propellers of this investigation, the use of sweep increases the effective values of section thickness ratio and design camber, that is, normal to the sweep line by a factor of $1/\cos \Lambda$. Consequently, the critical section Mach number (normal to sweep line) is reduced. A comparison of these factors for the swept and unswept blades is presented in figure 9. For most of the blade sections outboard of the knee, the section critical Mach number for the swept blade is about 8 percent lower than for the unswept blade. The increase, therefore, in the critical forward Mach number predicted by the use of simple infinite-span sweep theory for a sweep of 45° would be approximately 30 percent. The measured increase in critical forward Mach number was found to be only 25 percent of this theoretical value. This difference is probably due to the lack of sweep at the knee and the severe separation of the boundary layer on the outboard sections.

The separation of the boundary layer is associated with an outflow of the boundary-layer air. An effort was made to reduce this separation by retarding the outflow with several fence configurations attached chordwise to the rearward part of the upper surfaces of the blades from the 0.55-radius to the 0.70-radius station. The fences did not change the propeller characteristics at supercritical speeds. No other device or change in design has yet been proposed which might logically lead to significant improvement in the characteristics of the highly swept propeller.

The swept propeller, with its severe mechanical and structural problems, does not appear to be a practical method for improving propeller performance since the same moderate gains in performance can be obtained for unswept propellers having small-thickness-ratio blade sections.

Effect of advance ratio and forward Mach number on maximum efficiency.- The variation of maximum efficiency with advance ratio for the forward Mach numbers at which the propellers were investigated is shown in figure 10. Swept propellers A and B have essentially the same maximum efficiency for a given advance ratio and forward Mach number; consequently only the results for swept propeller A are presented in this figure. The dashed lines for forward Mach numbers of 0.85 and 0.90 represent the highest efficiencies measured for the swept propeller A and are not necessarily maximum efficiencies. Similar results for the straight propeller, reference 3, for forward Mach numbers of 0.80, 0.85, and 0.90 are shown for comparison. The trends in efficiency changes with advance ratio are similar for these propellers up to and including a forward Mach number of 0.85, except that the efficiencies for the swept propellers are higher than those for the straight propeller at supercritical forward Mach numbers. It was found that for forward Mach numbers above 0.80 it was necessary to operate the straight propeller at reduced values of advance ratio to obtain the highest efficiencies. No similar operational requirement is indicated for the swept propellers. The highest efficiencies for the swept propellers were obtained at the higher values of advance ratio for the speed range investigated.

Effect of forward Mach number on efficiency for constant power coefficient.- The variation of efficiency with advance ratio for constant values of power coefficient and forward Mach number is shown in figure 11 for the swept and straight propellers. In general, the results indicate that the highest efficiency for a given power coefficient is essentially the same for swept propellers A and B throughout the Mach number range. At forward Mach numbers above 0.7 and for constant values of power coefficient the highest efficiencies for the swept propellers are from 7 to 16 percent higher than those for the straight propeller.

CONCLUSIONS

Investigations of the NACA 4-(4)(06)-057-45A and NACA 4-(4)(06)-057-45B swept propellers and comparison of results with those for the NACA 4-(4)(06)-04 straight propeller through a forward Mach number range extending up to 0.925 indicate the following conclusions:

1. Only moderate delays in adverse compressibility effects were obtained through the use of large amounts of sweep. The measured delay was only about 25 percent of the value predicted by the use of the simple infinite-span sweep theory.

2. The small differences in pitch distribution for the swept propellers had little effect on maximum efficiency performance through the forward Mach number range.

3. The swept propellers were 10 percent more efficient than the straight propeller at a forward Mach number of 0.85 for the design blade angle of 60°.

4. At the highest forward Mach numbers reached in this investigation the highest efficiencies occurred at high values of advance ratio for the swept propellers and at low values of advance ratio for the straight propeller.

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REFERENCES

1. Delano, James B., and Carmel, Melvin M.: Investigation of the NACA 4-(5)(08)-03 Two-Blade Propeller at Forward Mach Numbers to 0.925. NACA RM L9G06a, 1949.

2. Delano, James B., and Morgan, Francis G., Jr.: Investigation of the NACA 4-(3)(08)-03 Two-Blade Propeller at Forward Mach Numbers to 0.925. NACA RM L9I06, 1949.

3. Delano, James B., and Harrison, Daniel E.: Investigation of the NACA 4-(4)(06)-04 Two-Blade Propeller at Forward Mach Numbers to 0.925. NACA RM L9I07, 1949.

4. Quick, A.: Tests on Airscrews with Swept Curved Blade Axes. Reps. and Translations No. 48, British M.A.P. Völkenrode, Jan. 1946. (Available from CADO, ATI 9086.)

5. Seiferth, R.: Investigation on an Airscrew with Swept Back Blade Tips at High Tip Speed. Reps. and Translations No. 102, British M.A.P. Völkenrode, April 1, 1946. (Available from CADO, ATI 7054.)

6. Holford, Fred R., and Kasley, J. H.: Flight Test Comparisons of Propeller with 836-14C2-18R1, 109390, 109494, and 109498 Blades in Level Flight Conditions. Rep. No. C-1795, Curtiss Propeller Div., Curtiss-Wright Corp., March 6, 1947.

7. Gray, W. H.: Wind-Tunnel Tests of a Swept-Blade Propeller and Related Straight Blades Having Thickness Ratios of 5 and 6 Percent. NACA RM L8H19, 1948.

8. Evans, Albert J., and Klunker, E. Bernard: Preliminary Investigation of Two Full-Scale Propellers to Determine the Effect of Swept-Back Blade Tips on Propeller Aerodynamic Characteristics. NACA RM L6J21, 1947.

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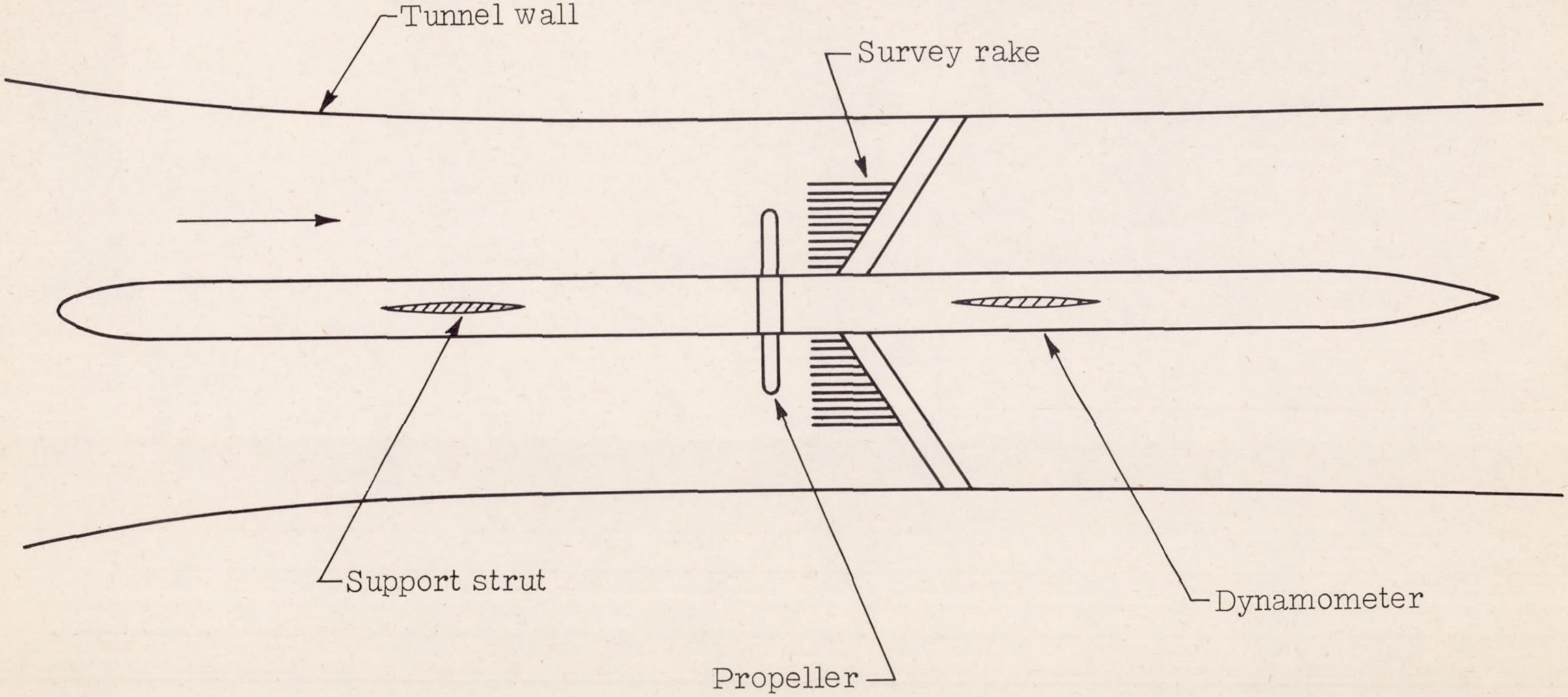

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Figure 1.– Test apparatus.

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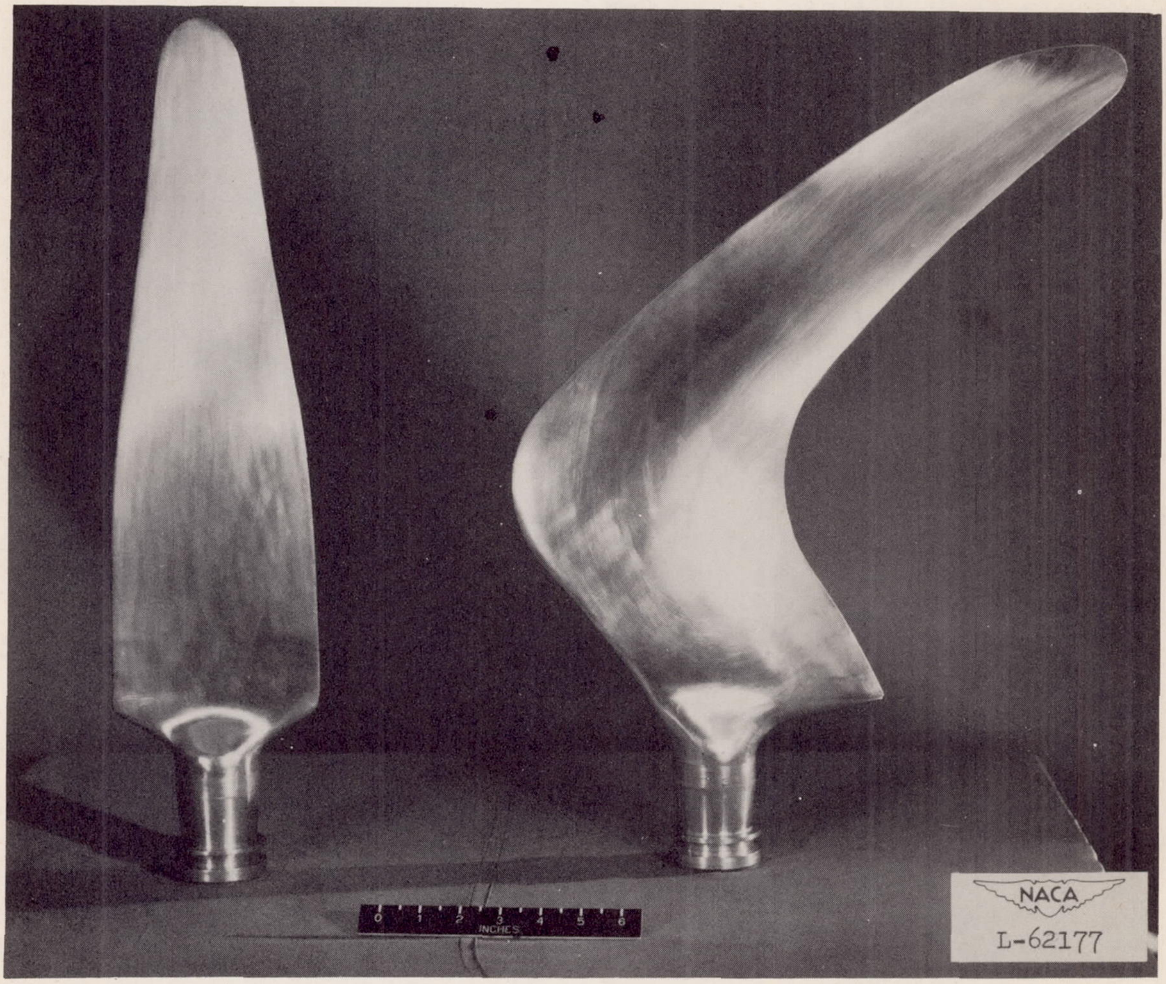

(a) NACA 4–(4)(06)–04 and 4–(4)(06)–057–45A propellers.

Figure 2.– Propeller blades used in sweep investigation.

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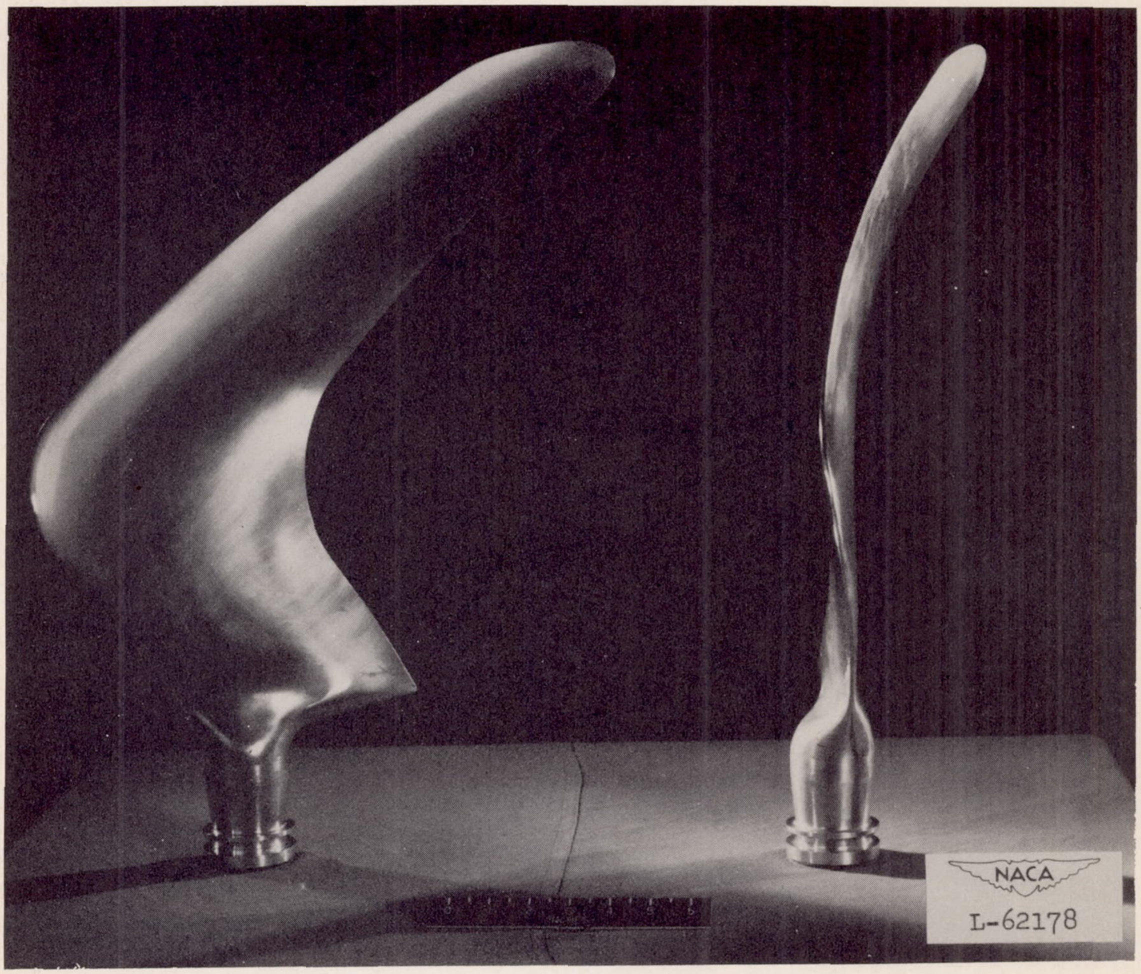

(b) NACA 4-(4)(06)-057-45A propeller.

Figure 2.- Concluded.

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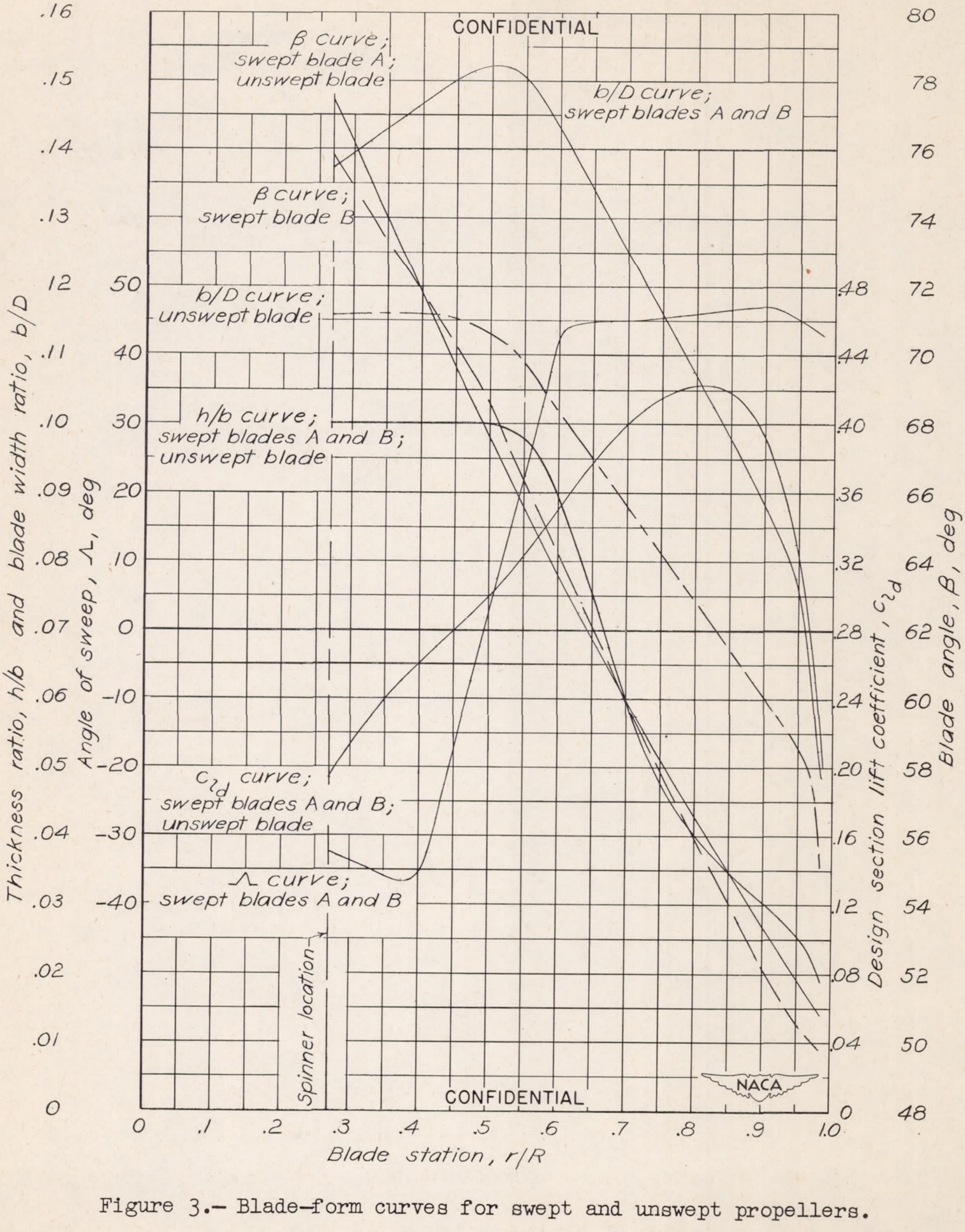

Figure 3.- Blade-form curves for swept and unswept propellers.

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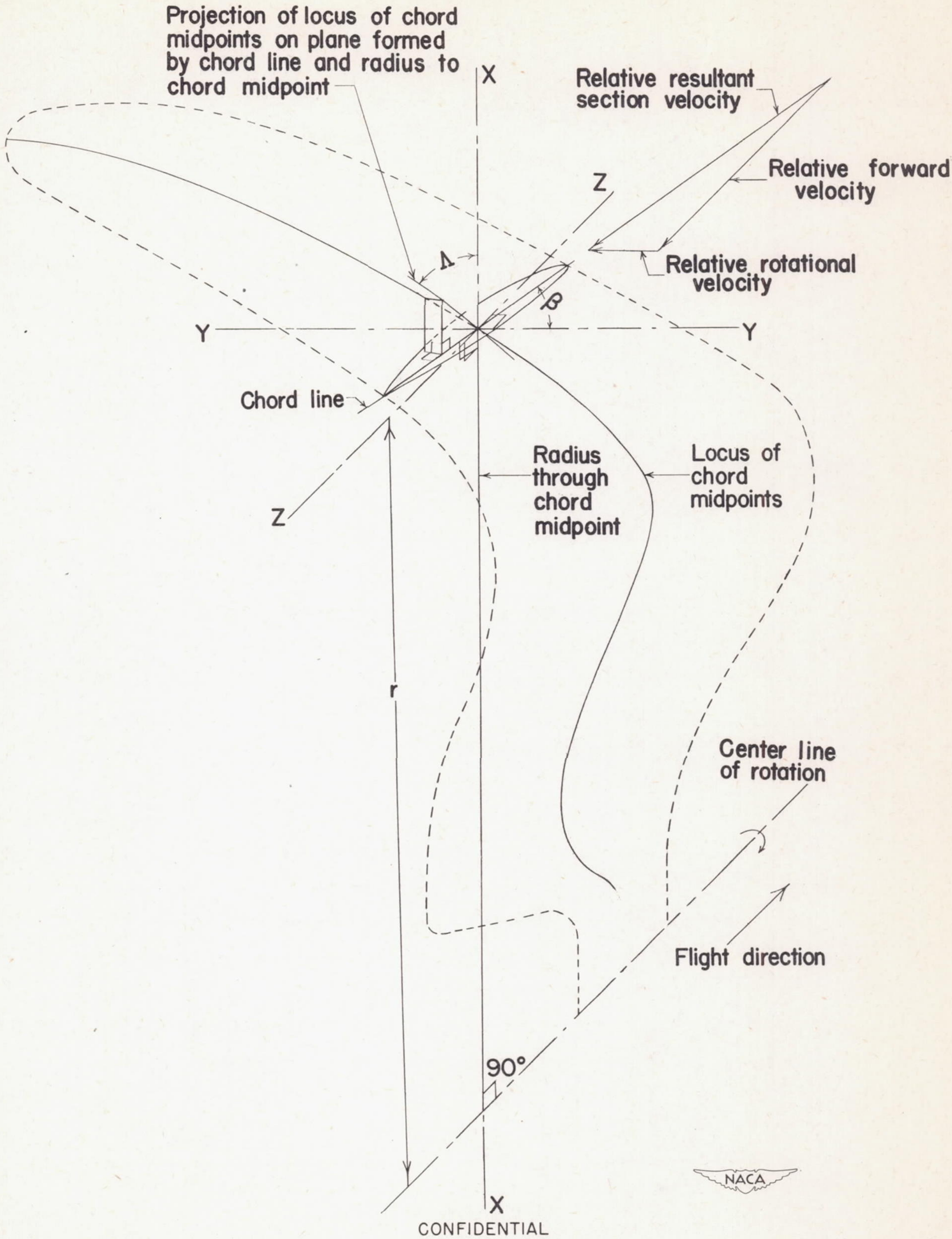

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Figure 4.– Illustration of blade-section orientation and definition of section sweep angle. X–X, Y–Y, and Z–Z are orthogonal axes.

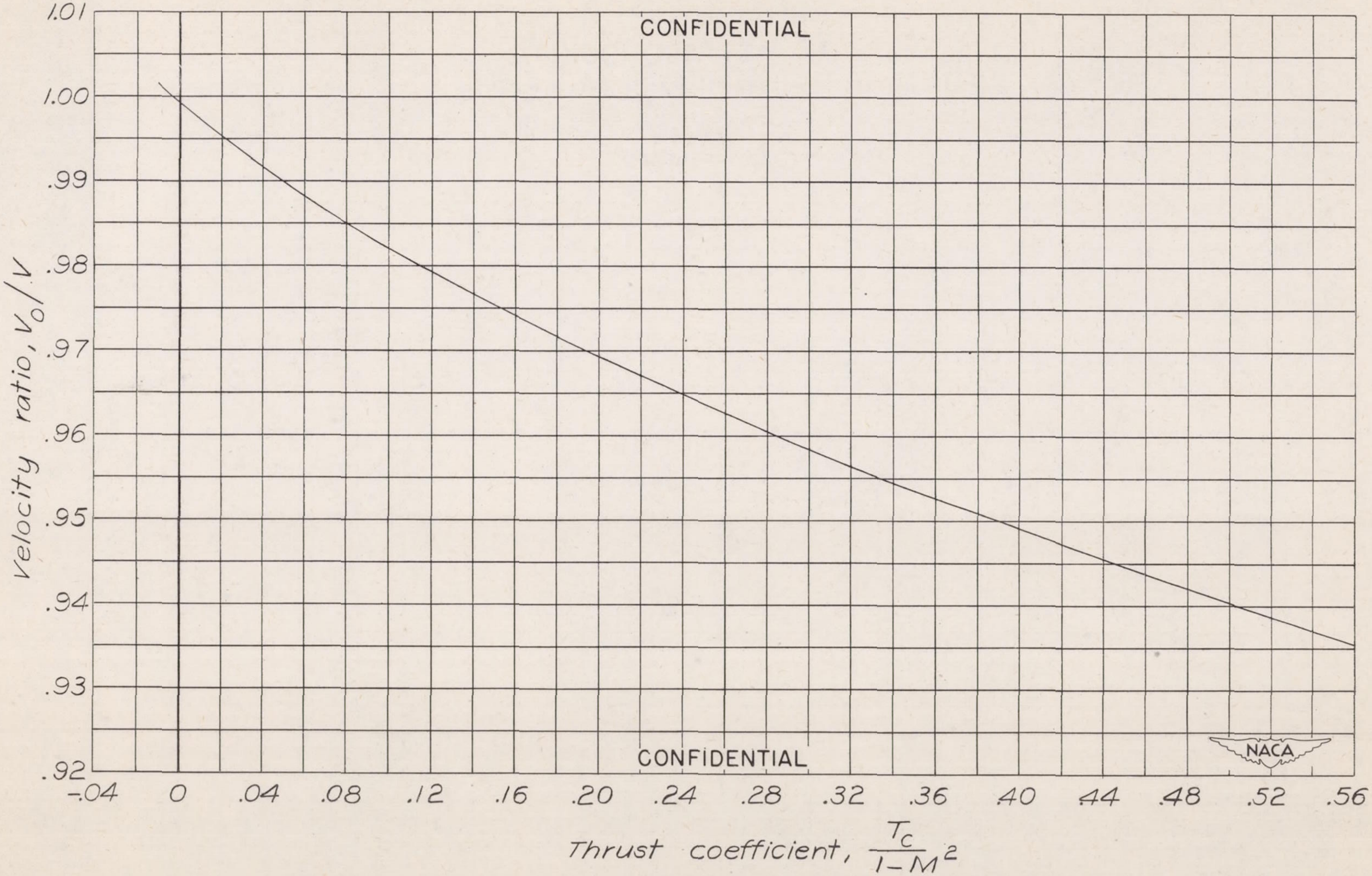
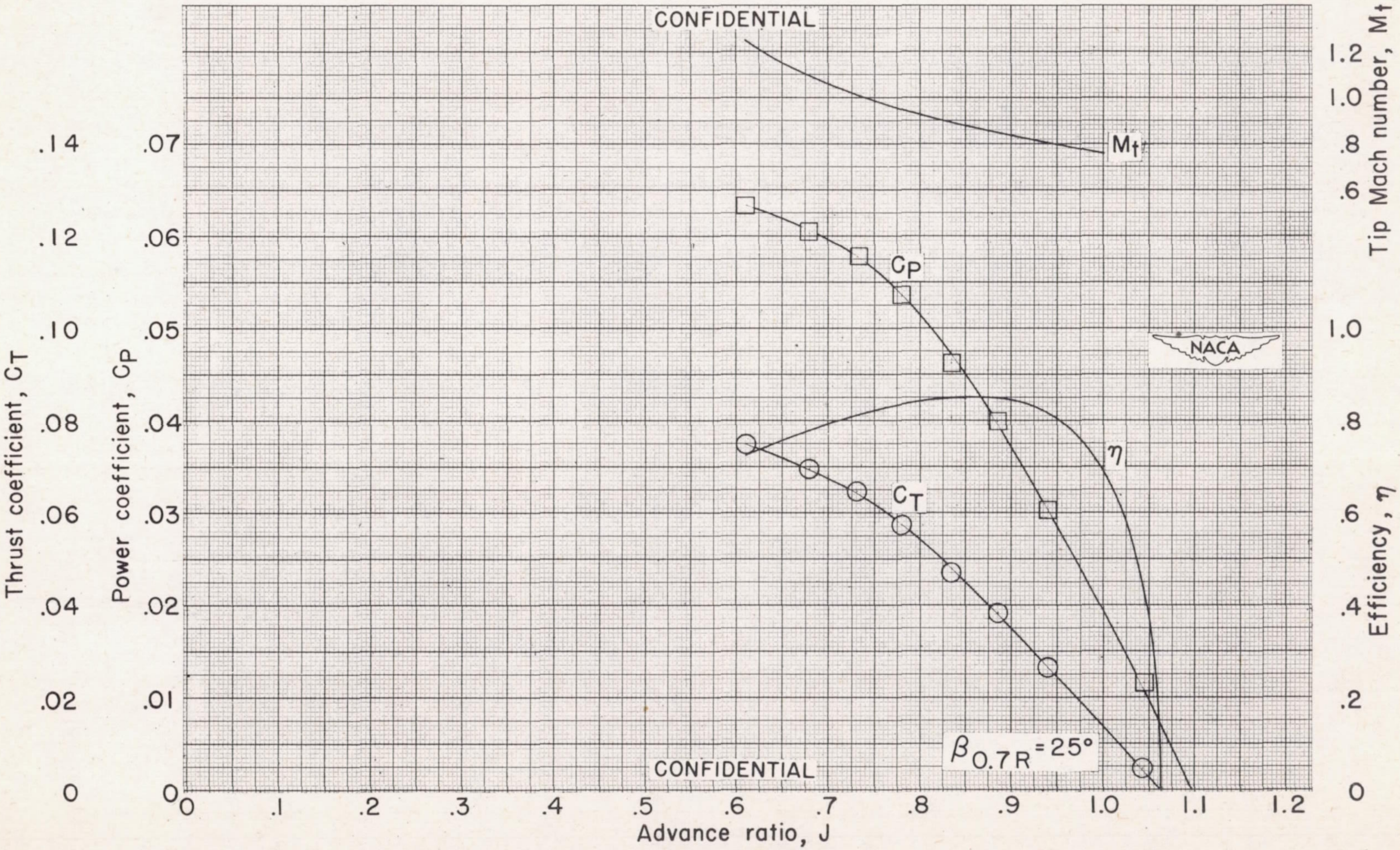
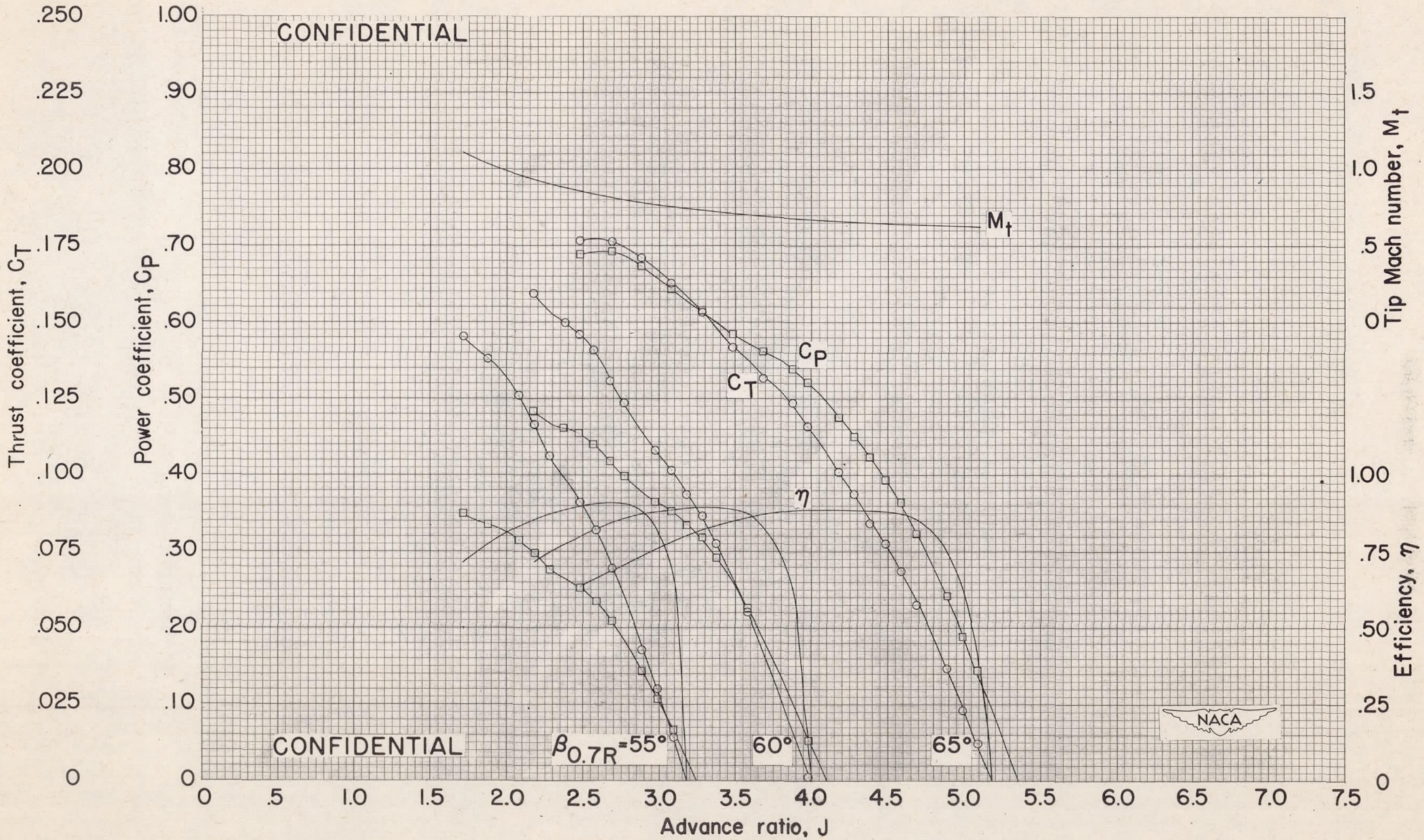


Figure 5.- Tunnel-wall-interference correction for 4-foot-diameter propeller in Langley 8-foot high-speed tunnel.



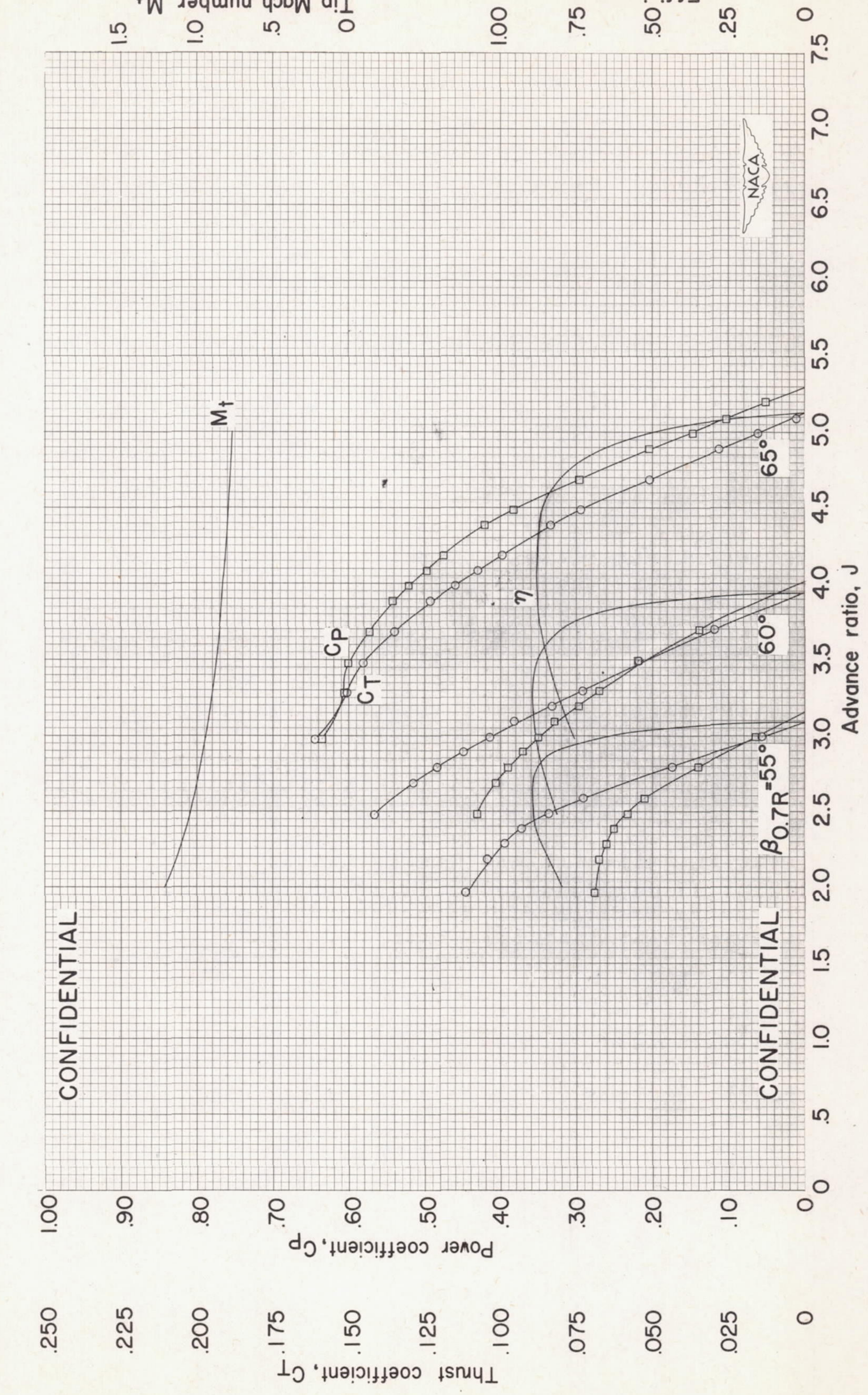
(a) M = 0.23.

Figure 6 .- Characteristics of NACA 4-(4)(06)-057-45A propeller.



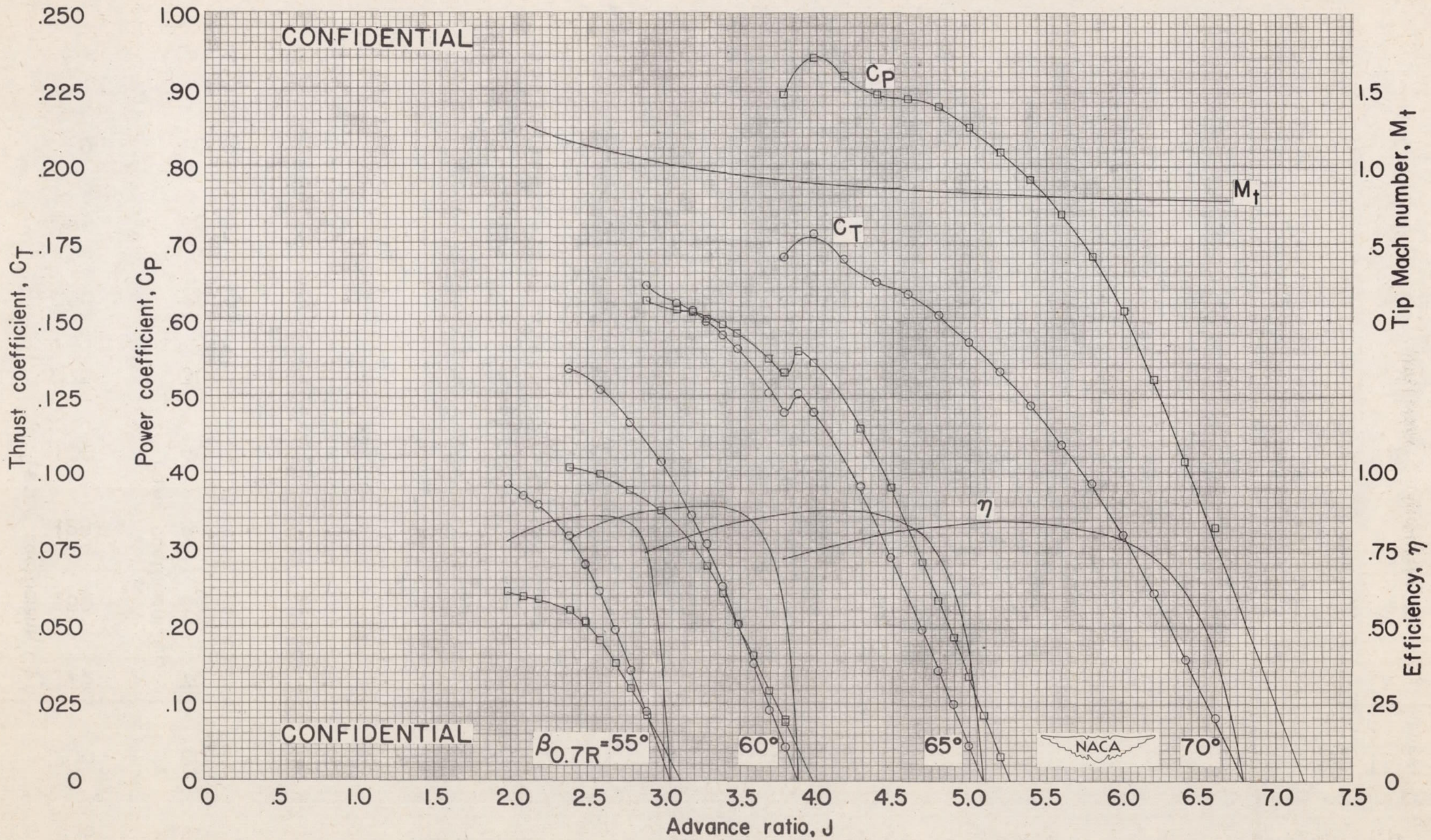
(b) M=0.53.

Figure 6 .- Continued.



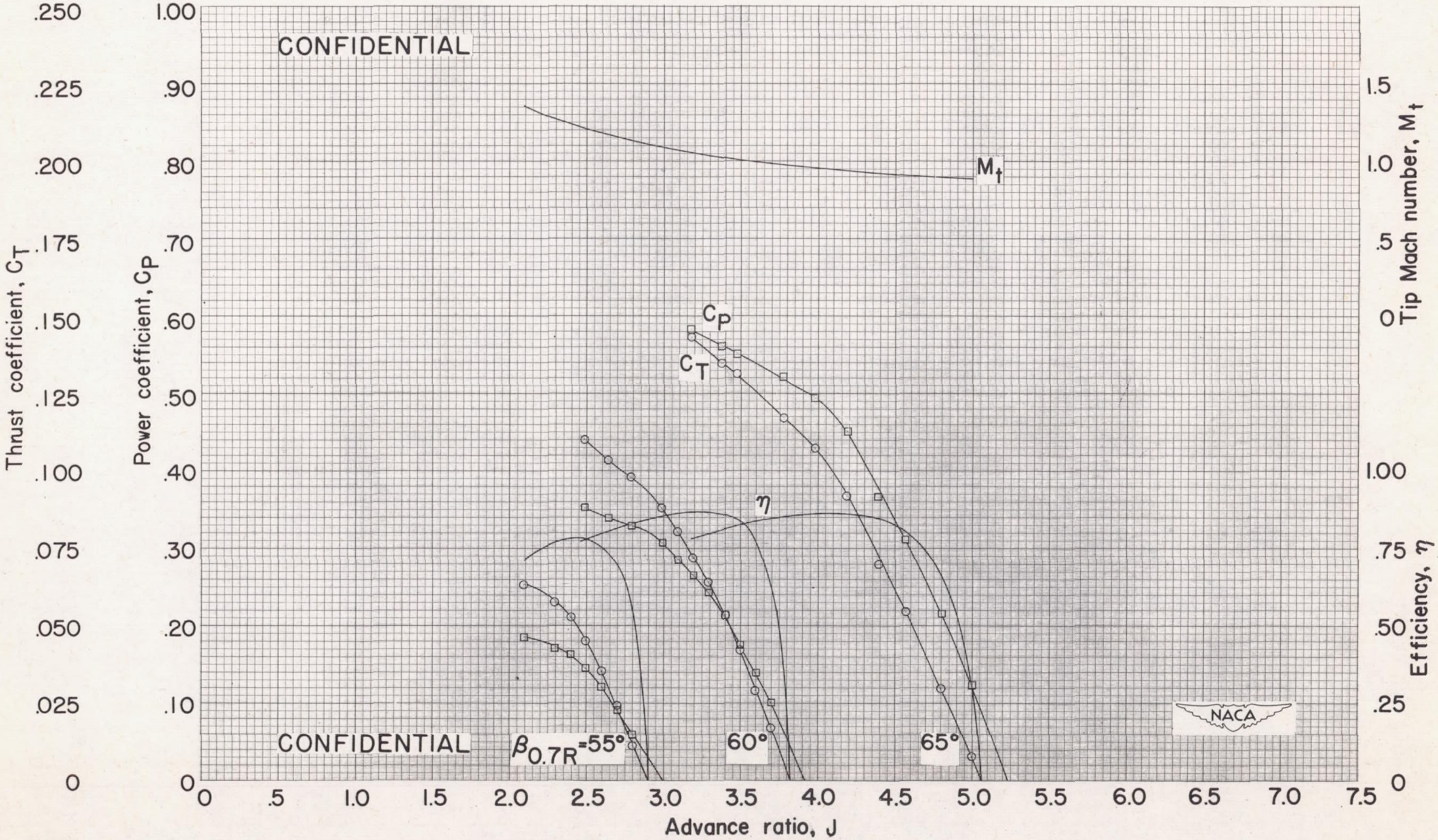
(c) M=0.65.

Figure 6 .- Continued.



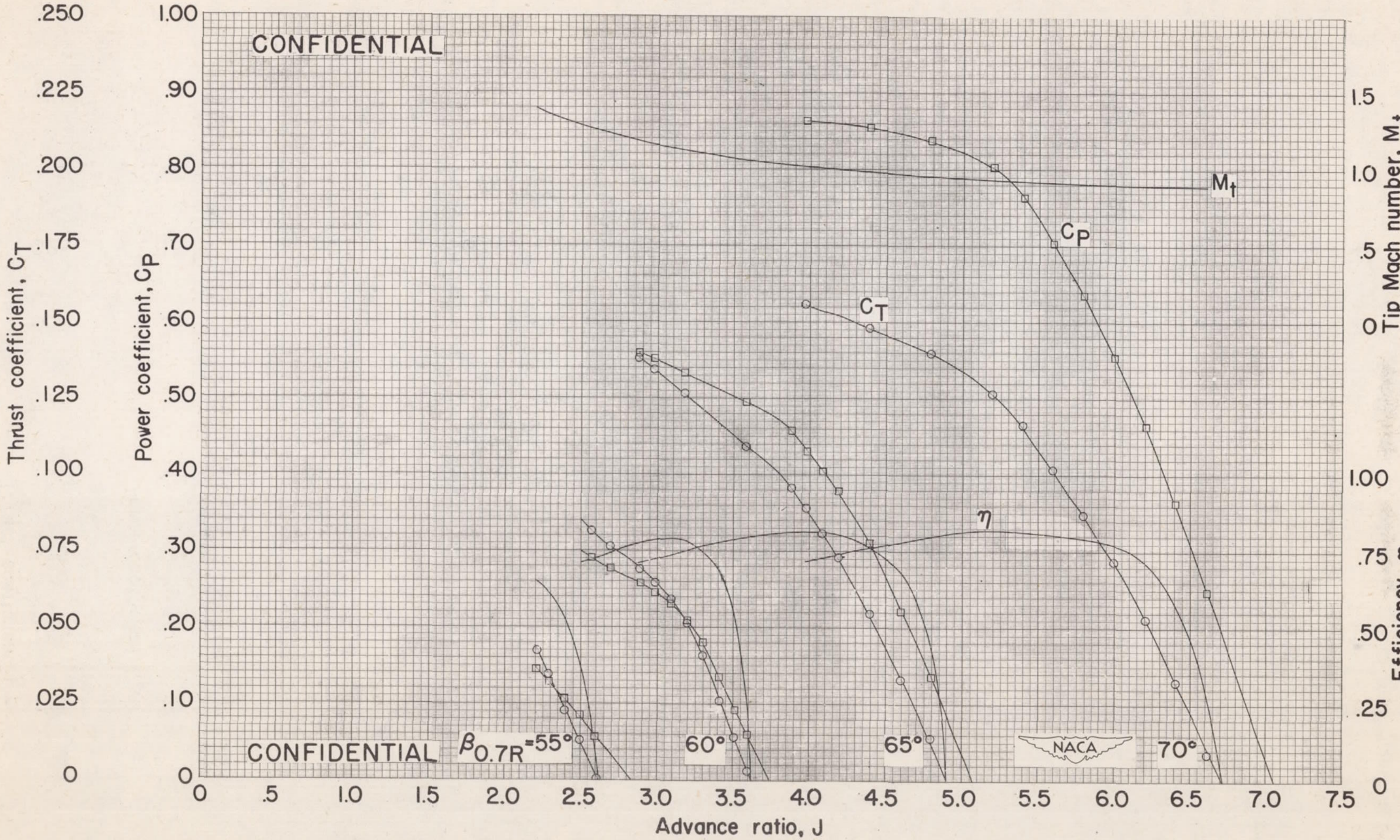
(d) M=0.70.

Figure 6 - Continued.



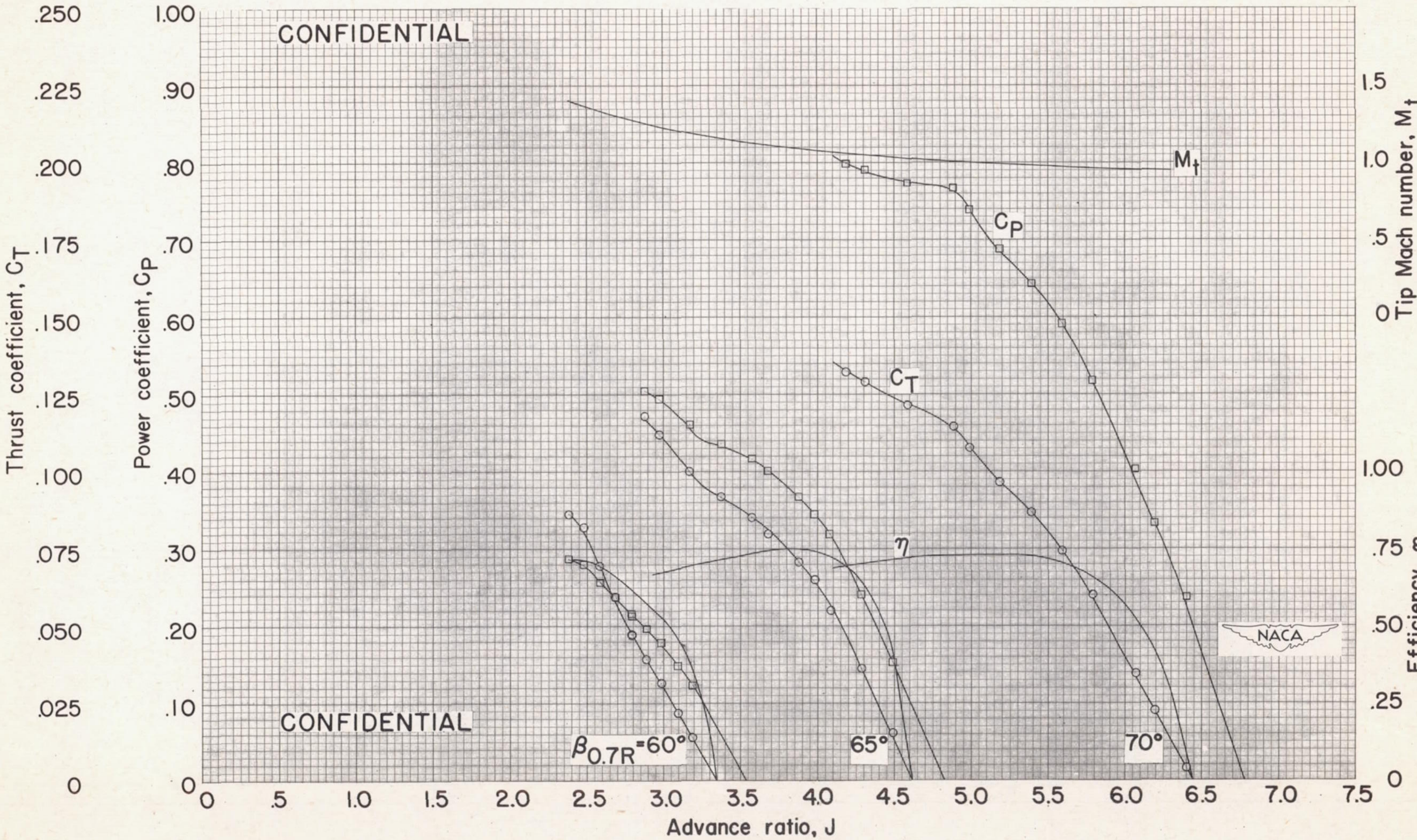
(e) M=0.75.

Figure 6 .- Continued.



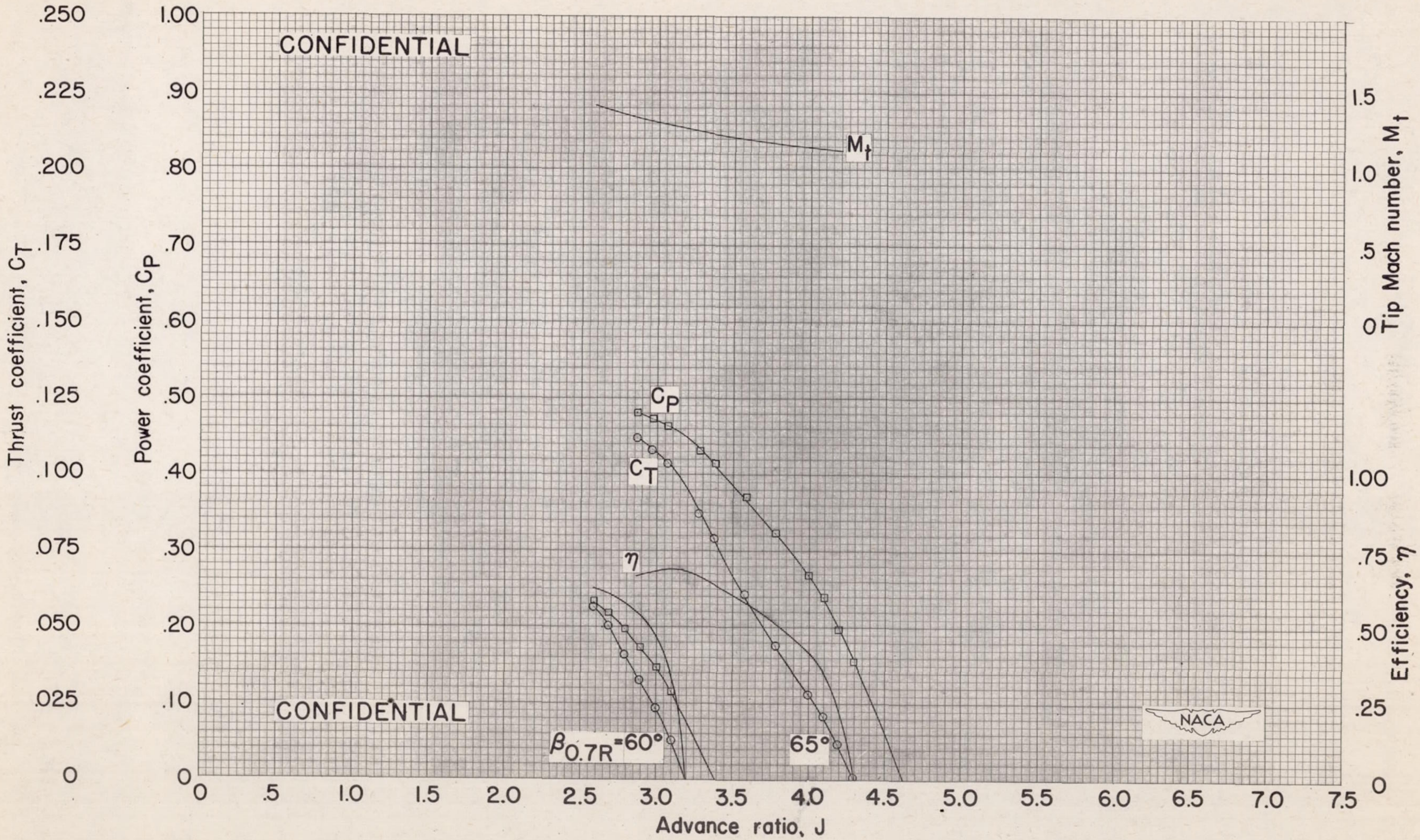
(f) M=0.80.

Figure 6 - Continued.



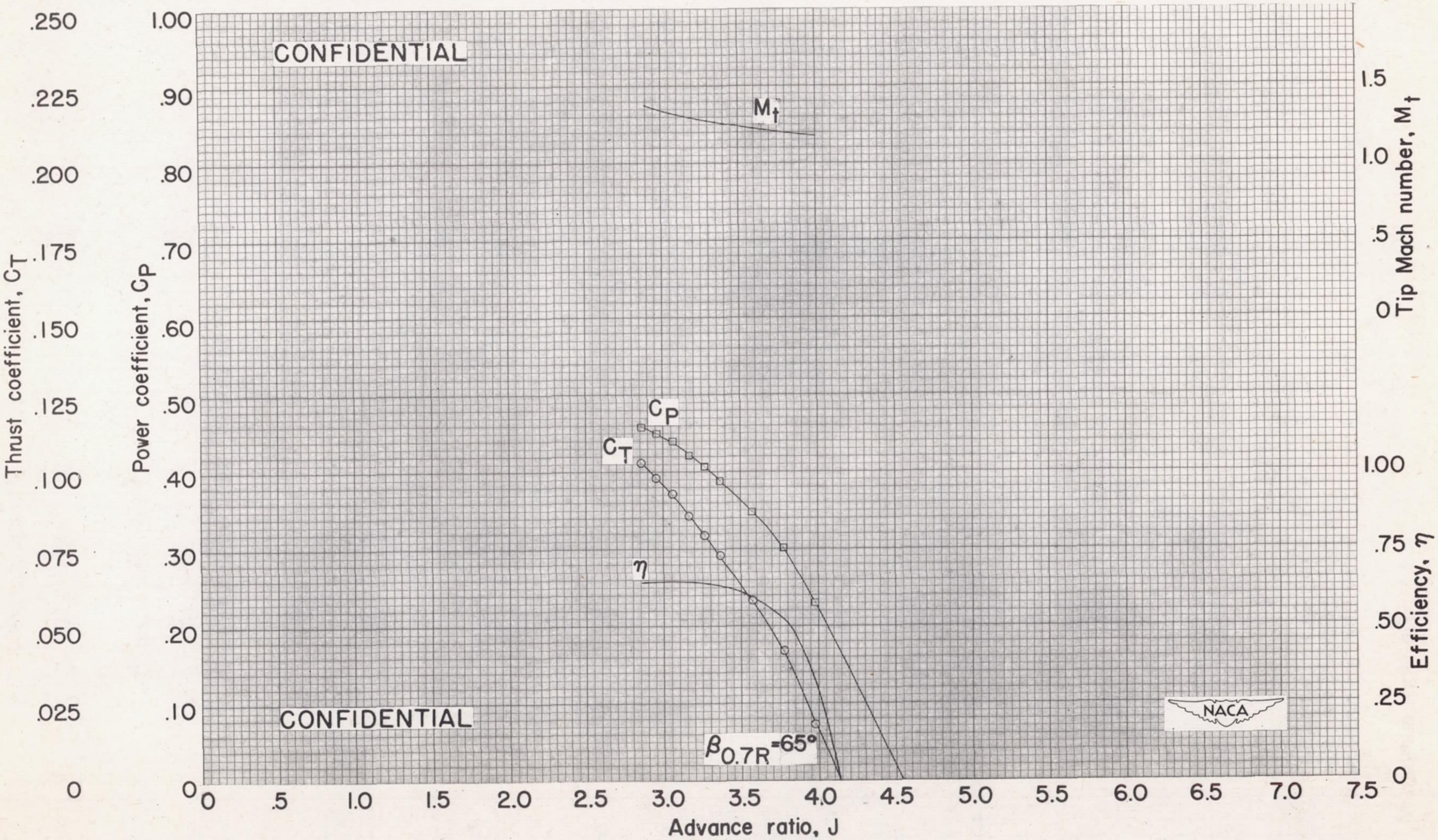
(g) M=0.85.

Figure 6 .- Continued.



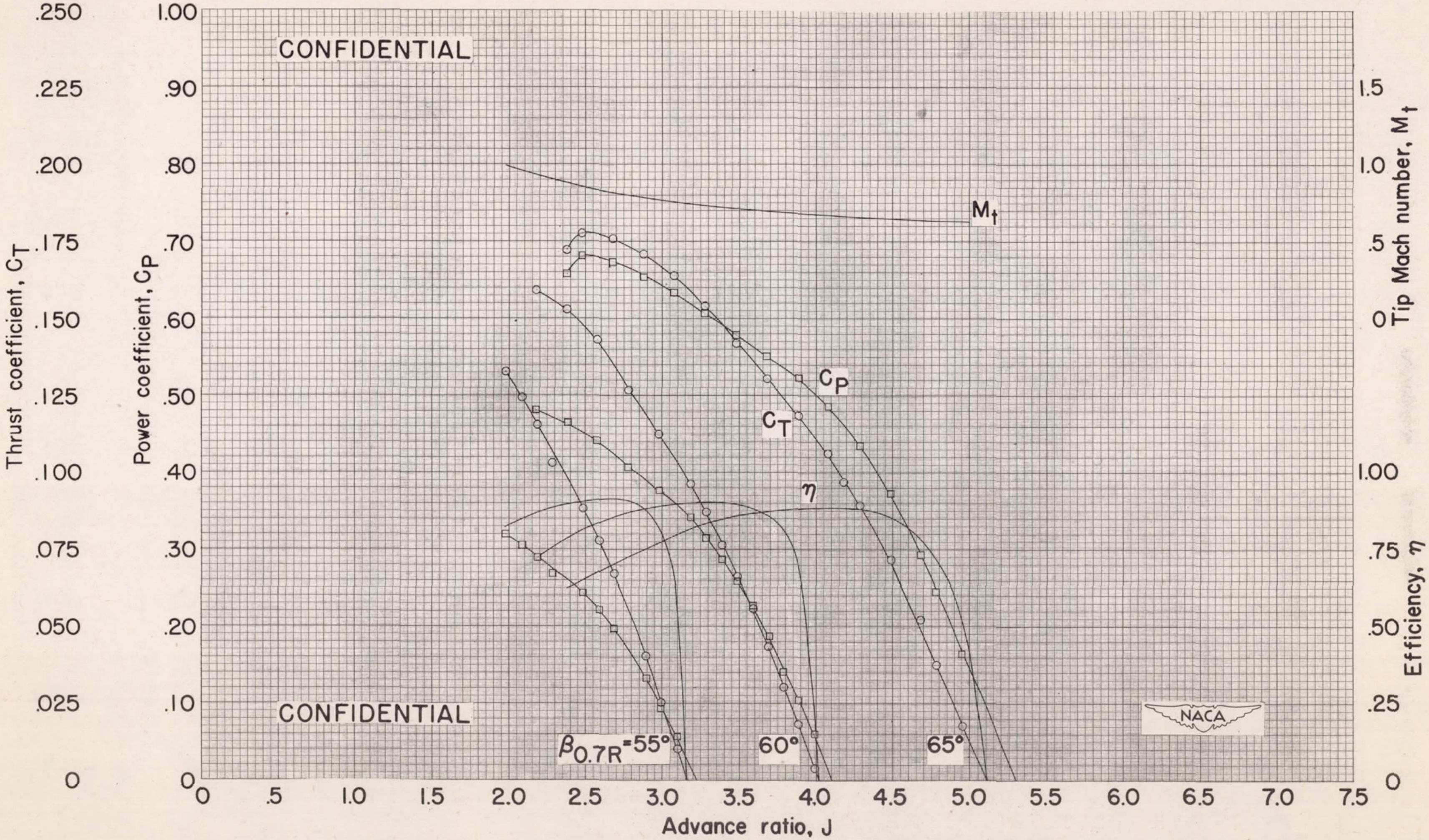
(h) M=0.90.

Figure 6 .- Continued.



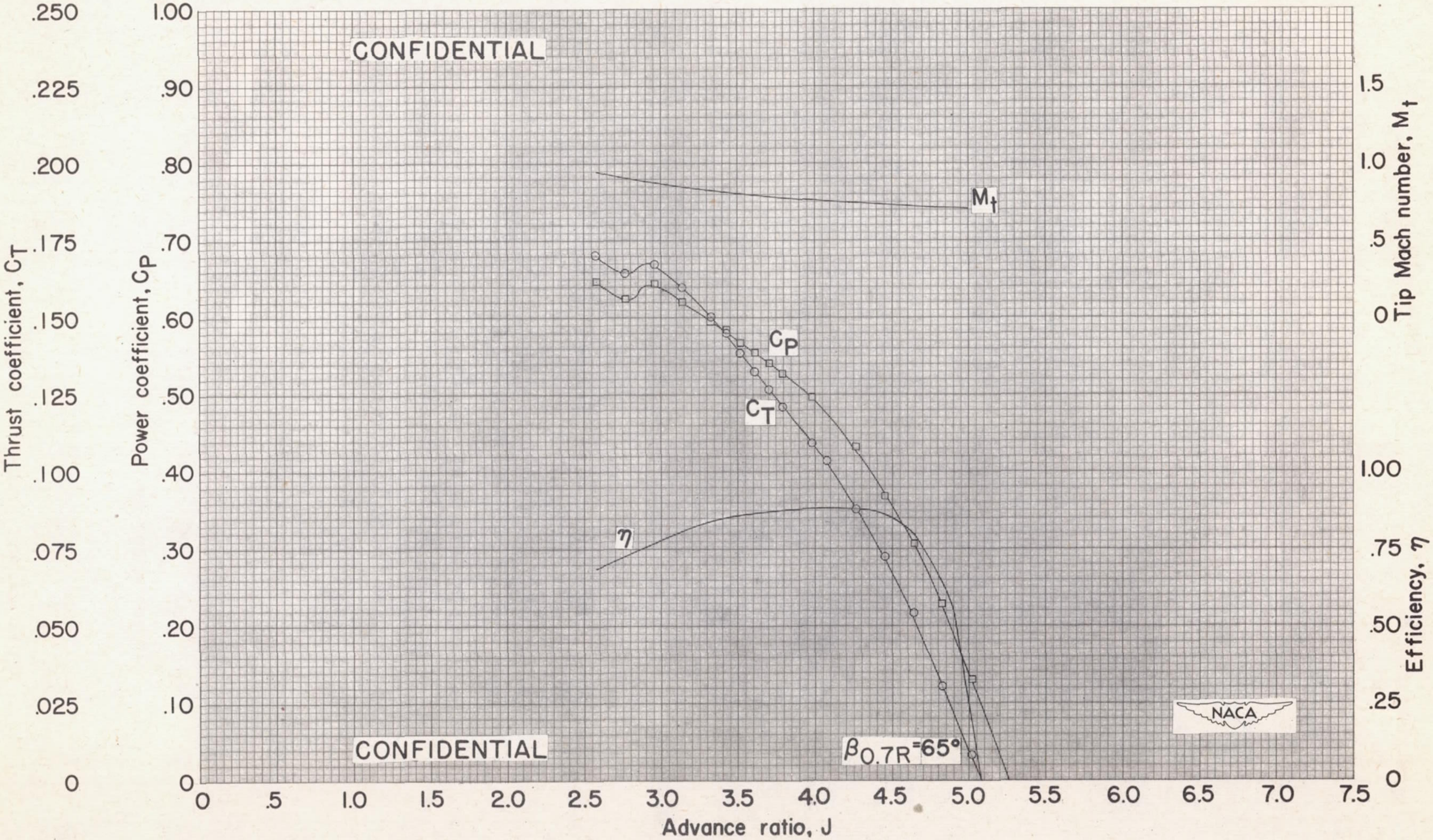
(i) M=0.925.

Figure 6 - Concluded.



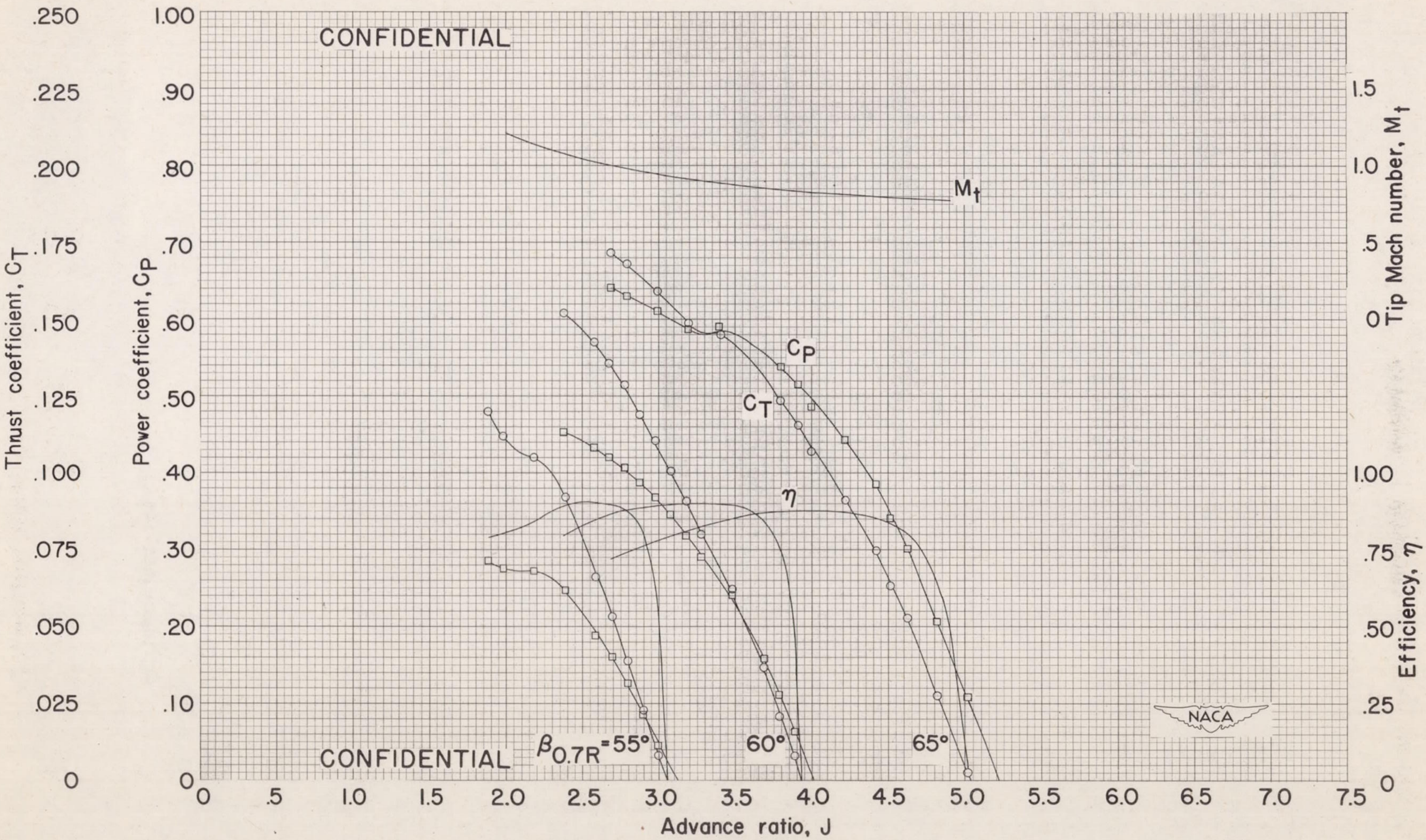
(a) M=0.53.

Figure 7.—Characteristics of NACA 4-(4)(06)-057-45B propeller



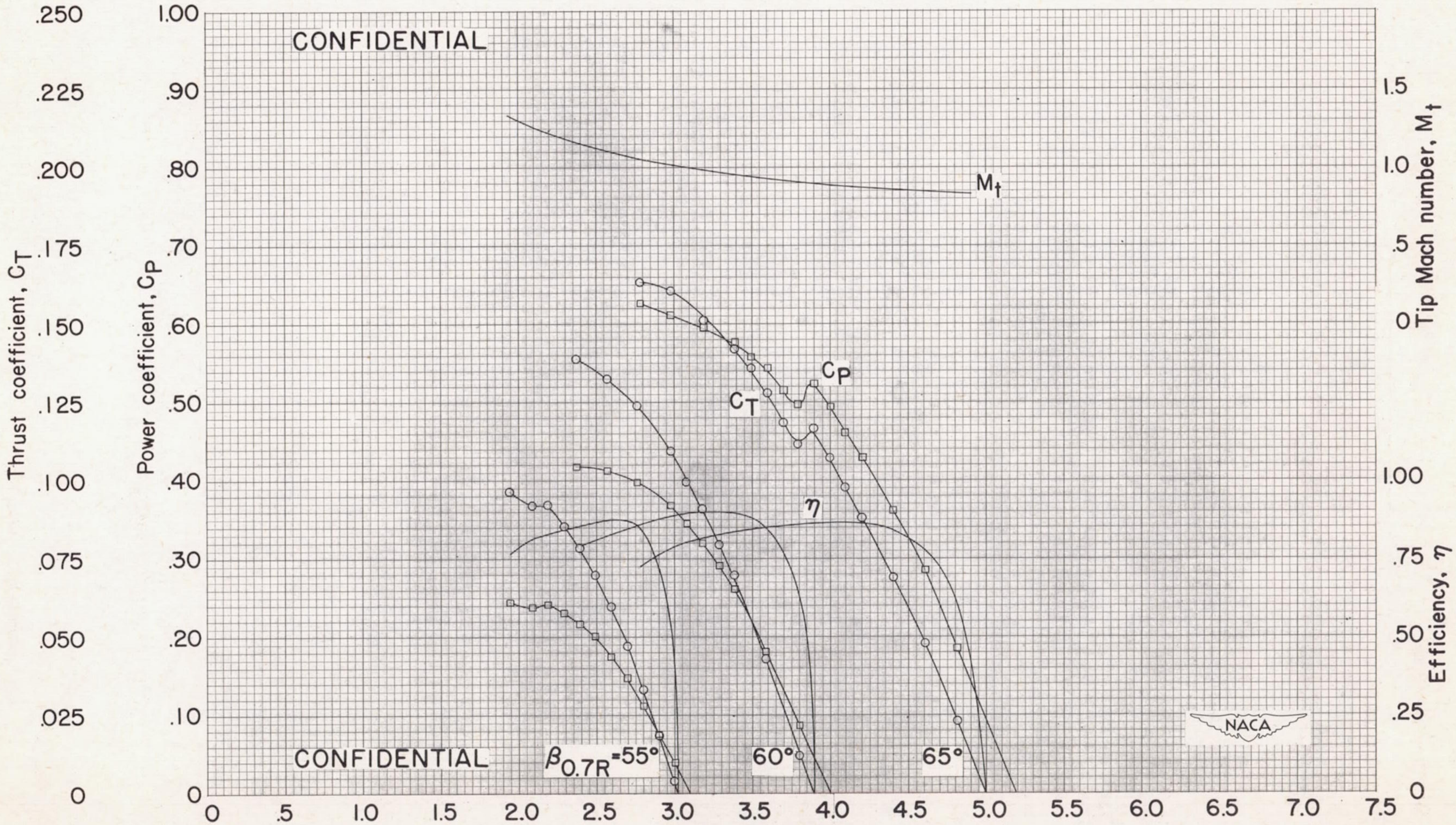
(b) M=0.60.

Figure 7 .- Continued.



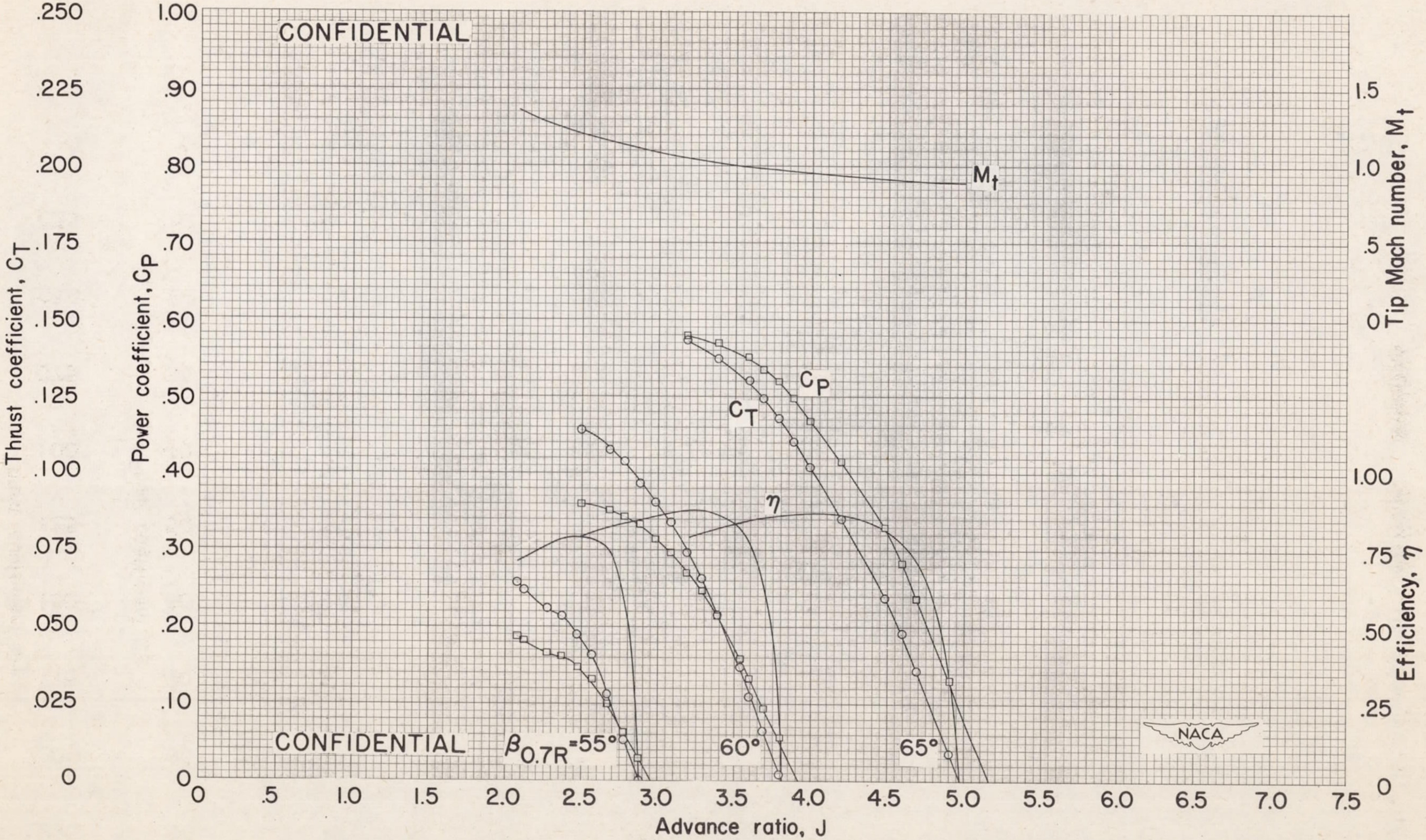
(c) M=0.65.

Figure 7 .- Continued.



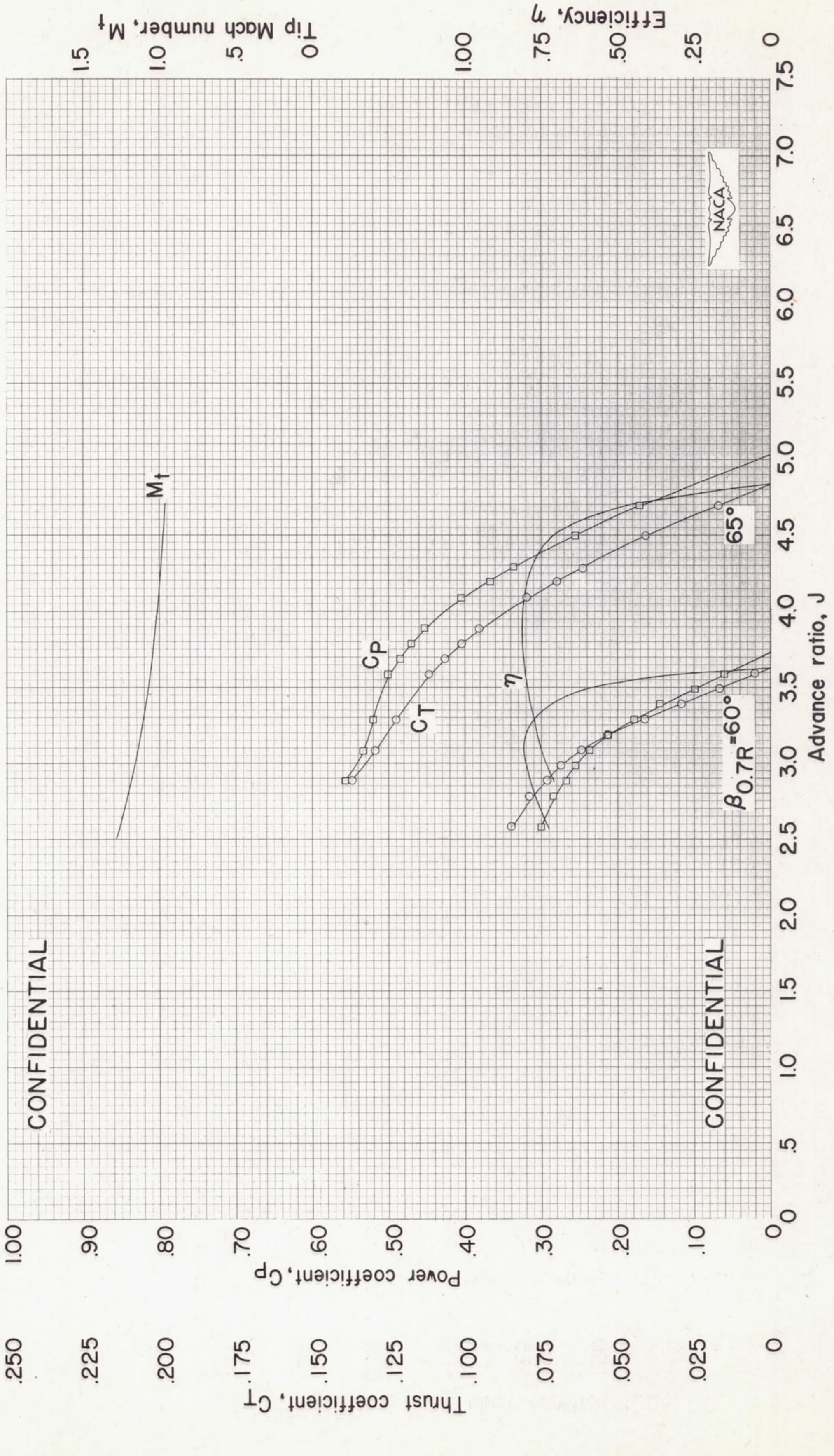
(d) M=0.70.

Figure 7 .- Continued.



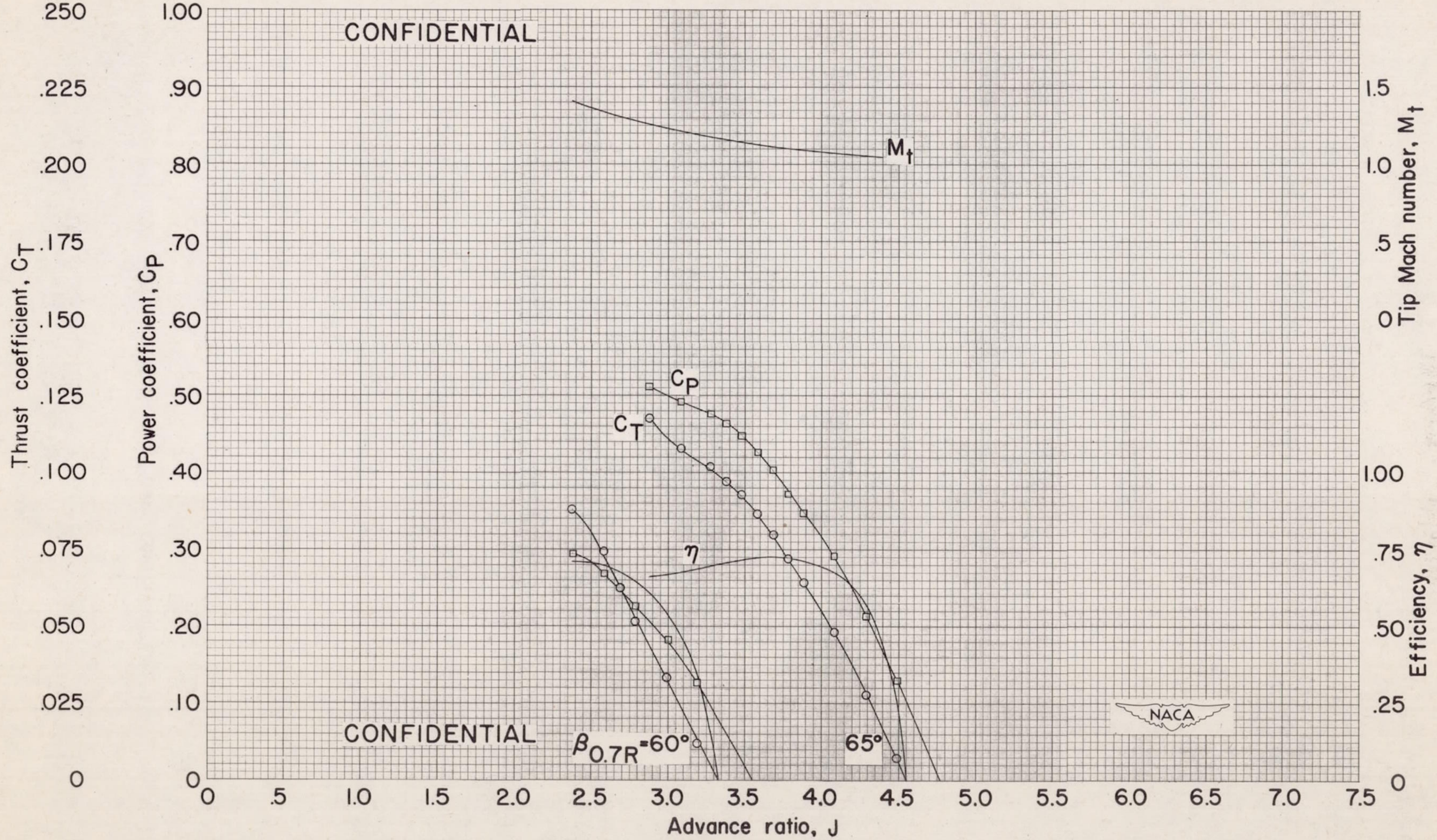
(e) M=0.75.

Figure 7 .- Continued.



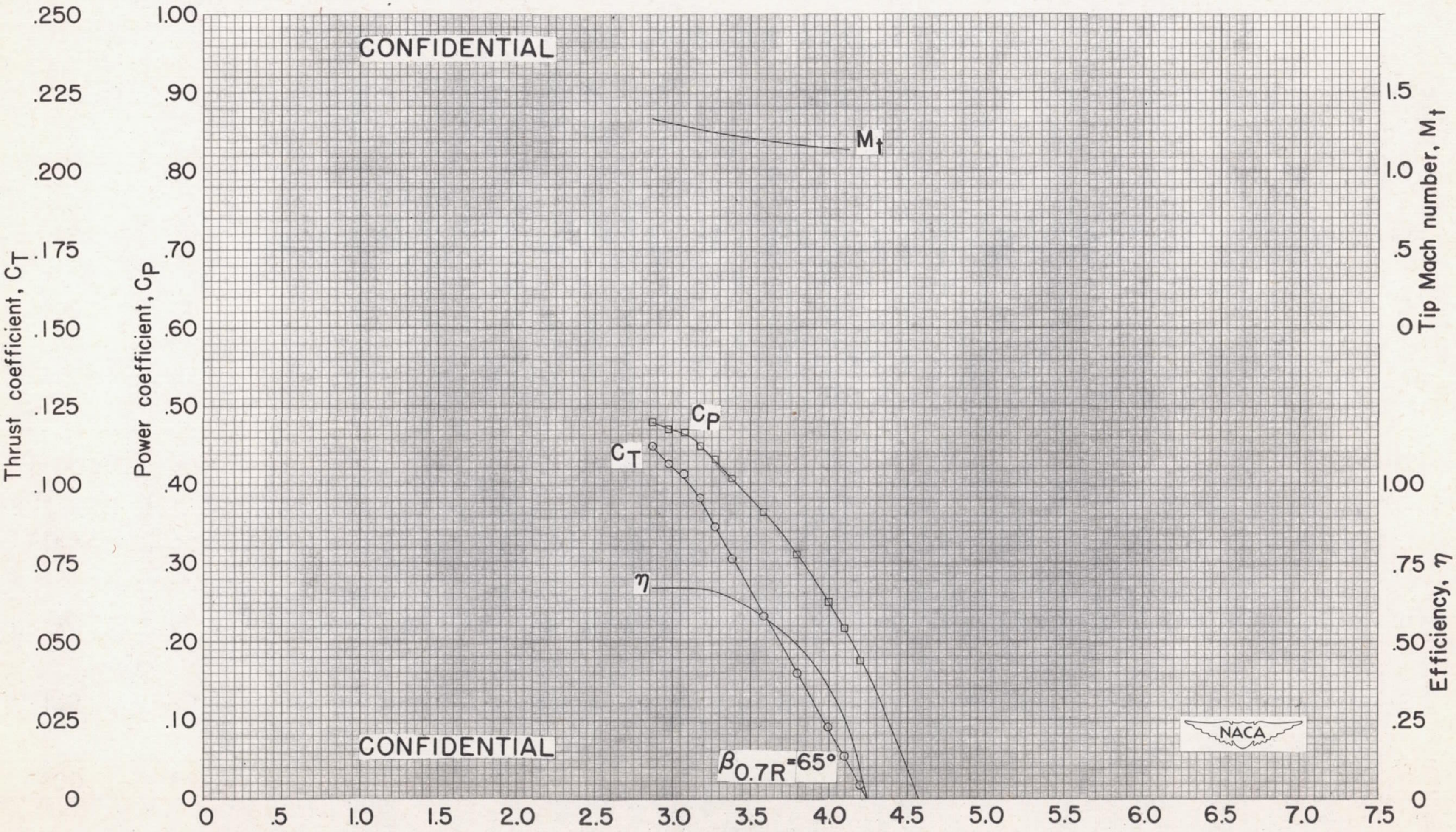
(f) M=0.80.

Figure 7 .- Continued.



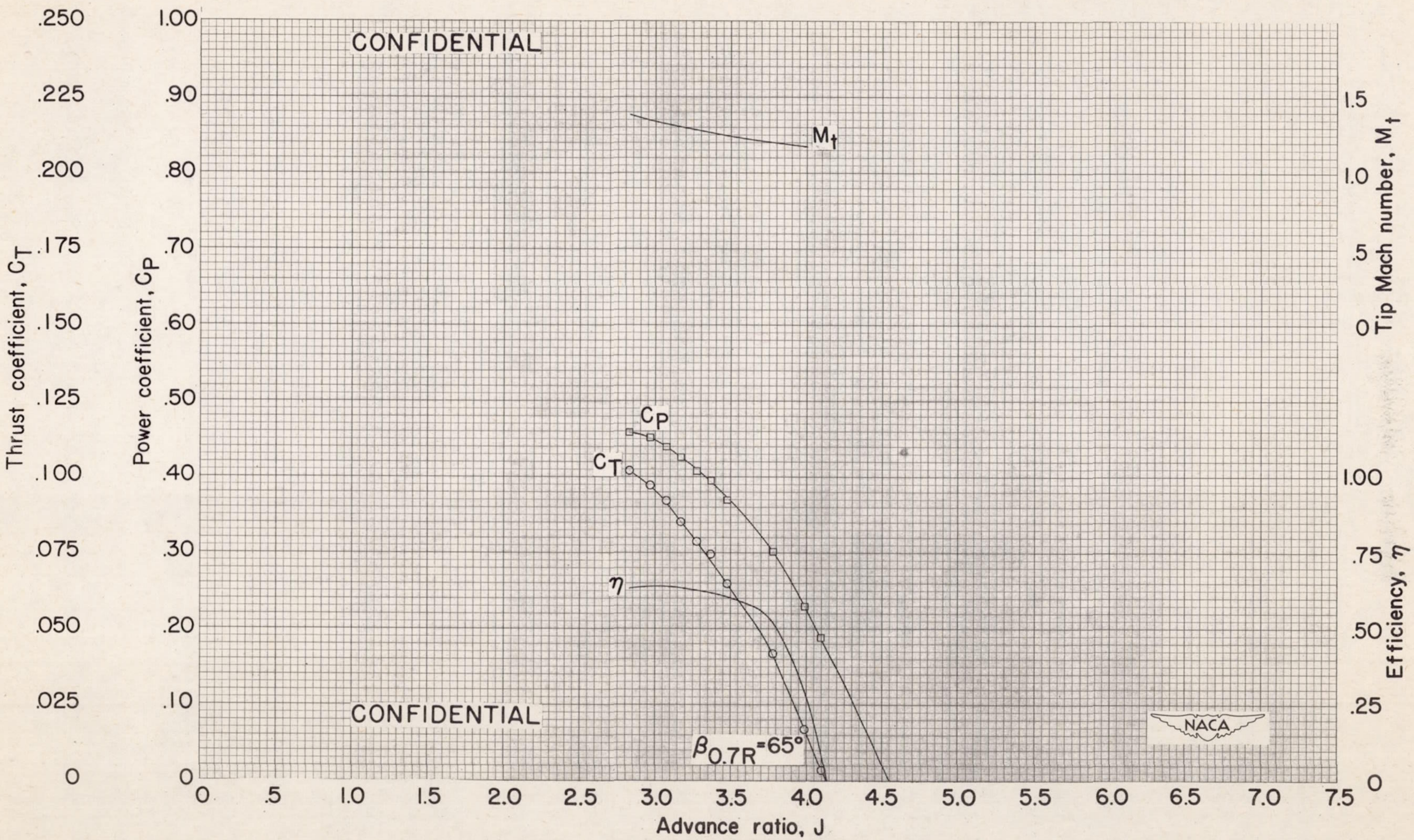
(g) M=0.85.

Figure 7 .- Continued.



(h) M=0.90.

Figure 7 .- Continued.



(i) M=0.925.

Figure 7 .- Concluded.

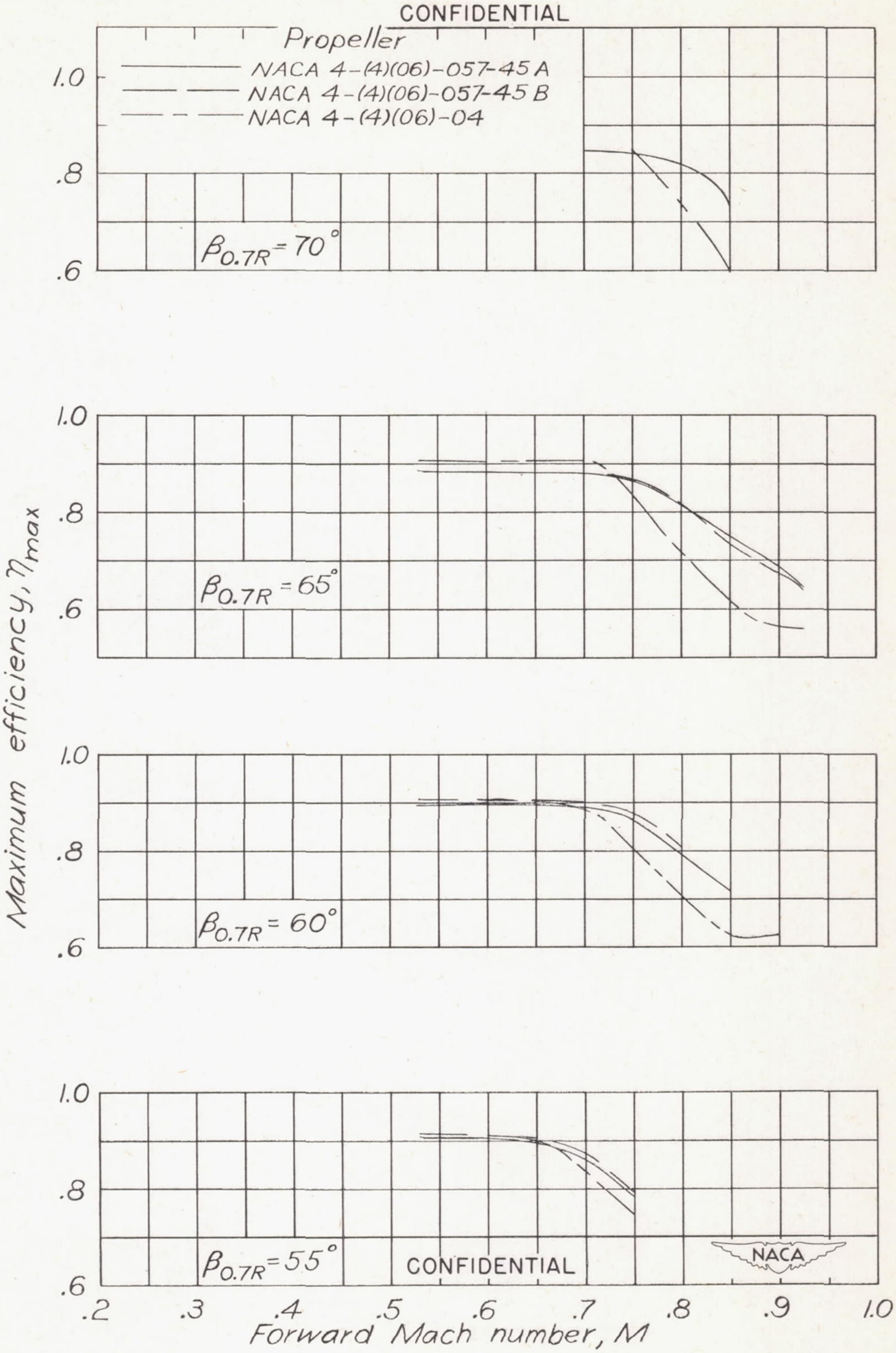


Figure 8.- Effect of forward Mach number on maximum efficiency.

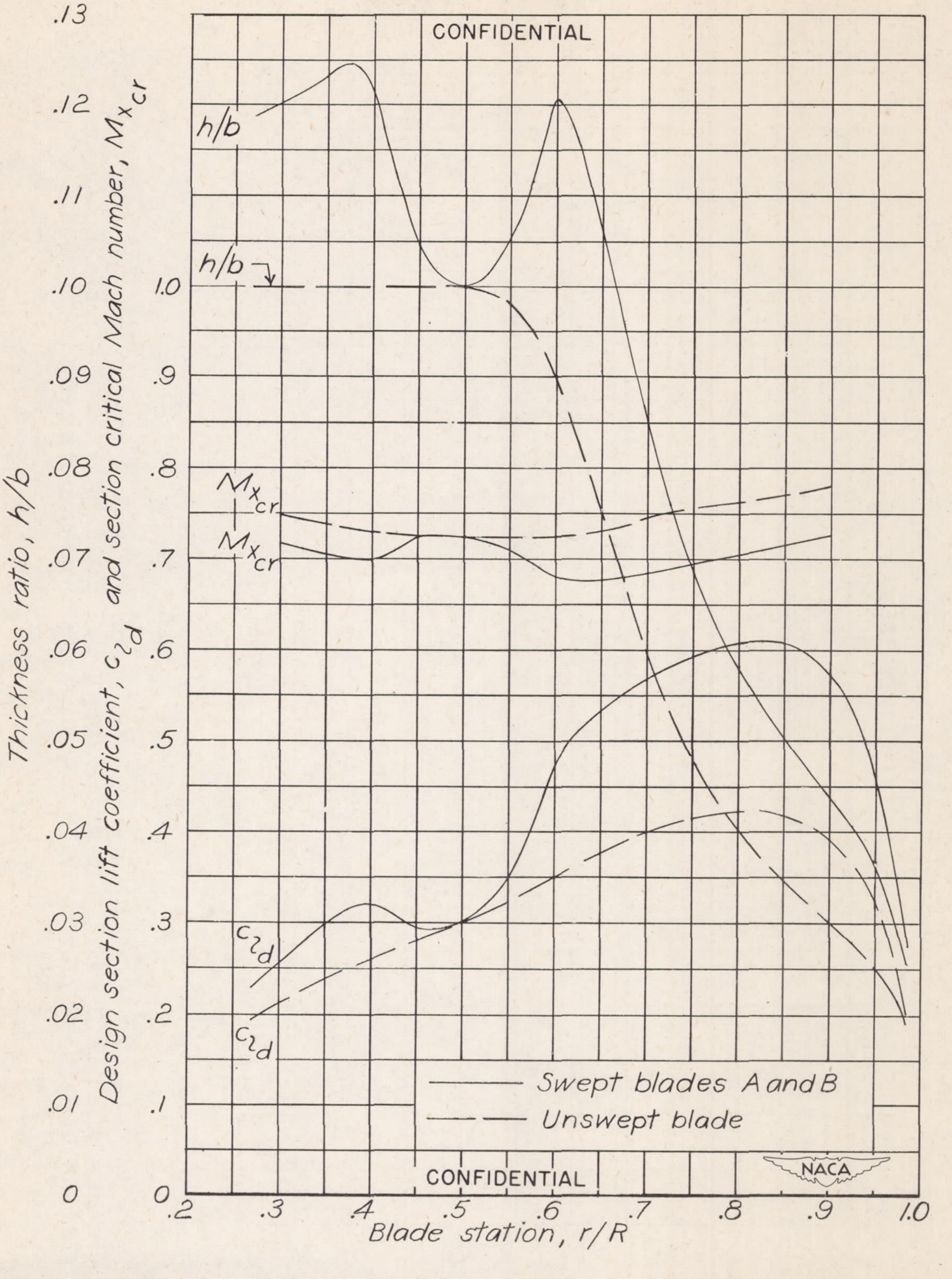


Figure 9.- Effective thickness ratio and design section lift coefficient of swept and unswept blades.

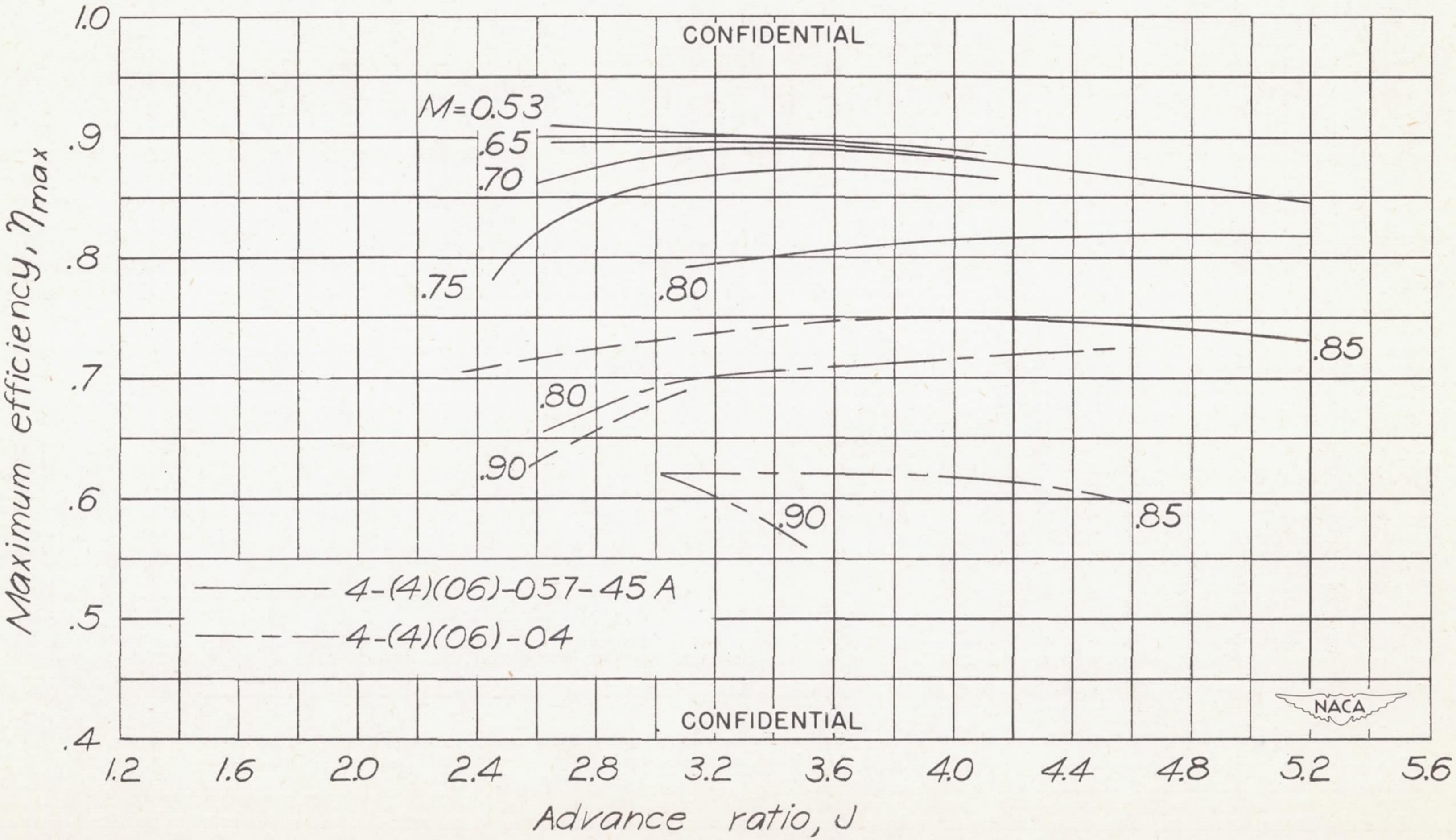
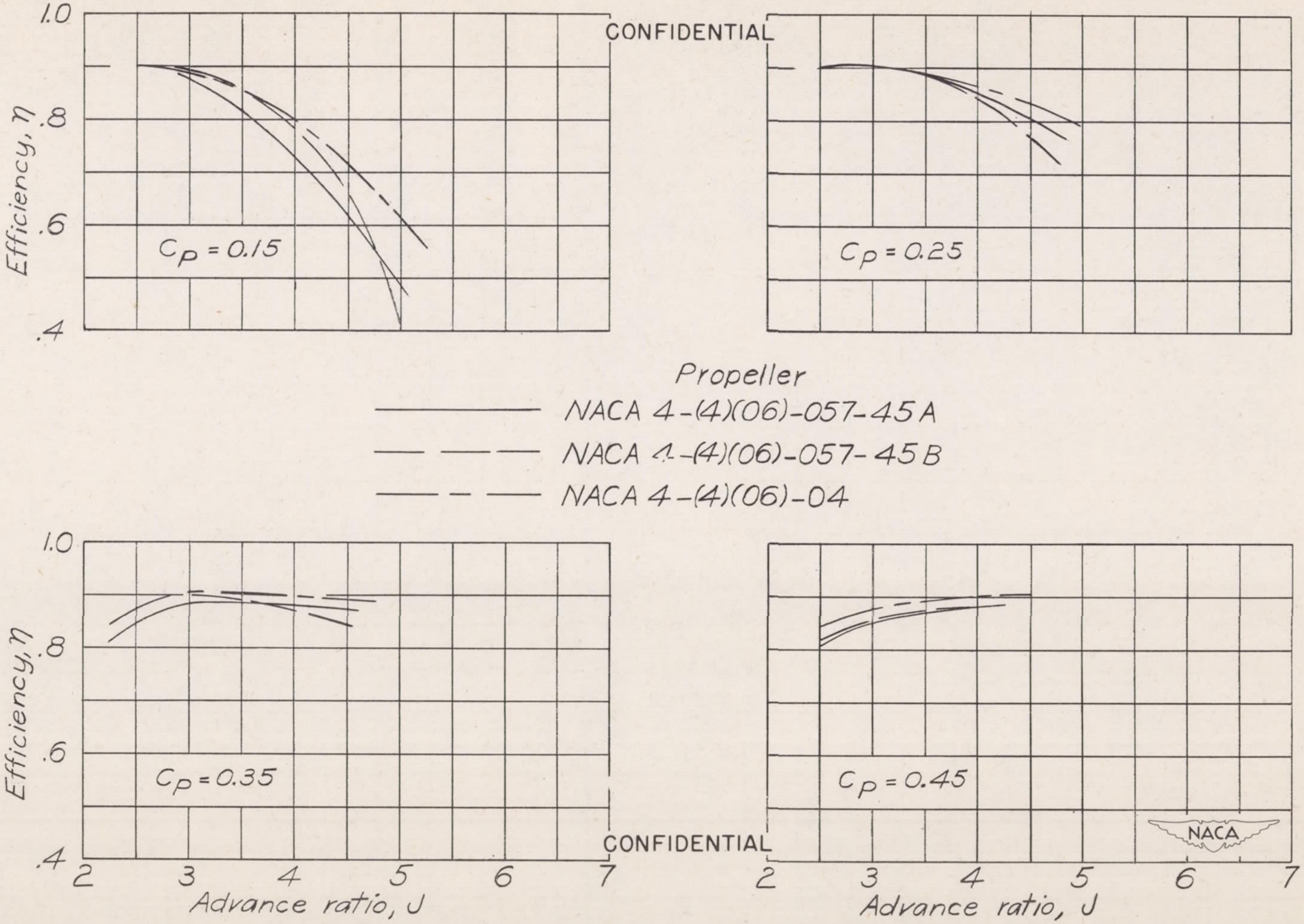
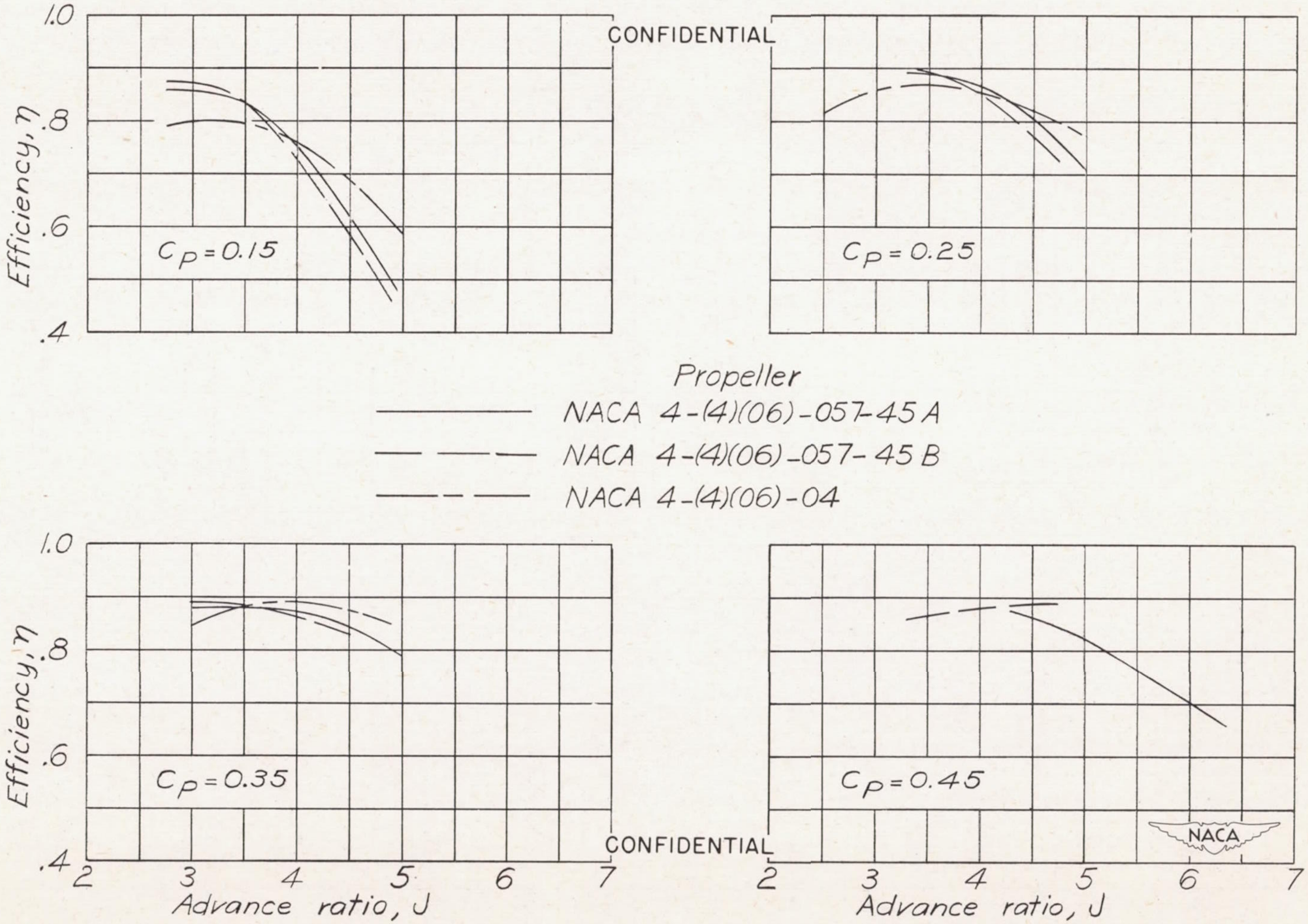


Figure 10.- Effect of forward Mach number and advance ratio on maximum efficiency. (Dashed lines indicate highest efficiencies measured, and are not necessarily maximum efficiencies.)



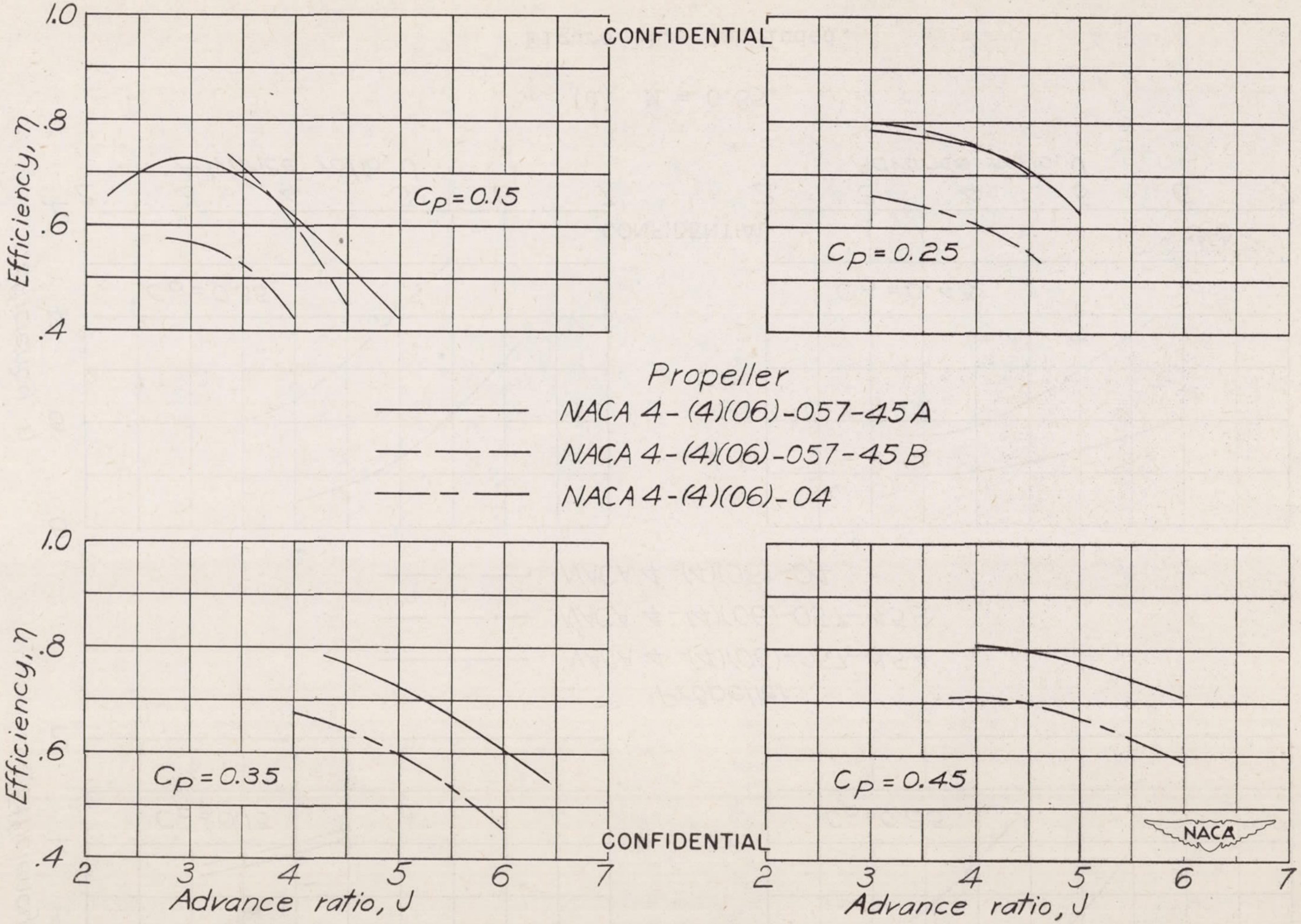
(a) M = 0.53.

Figure 11.- Effect of power coefficient and advance ratio on efficiency.



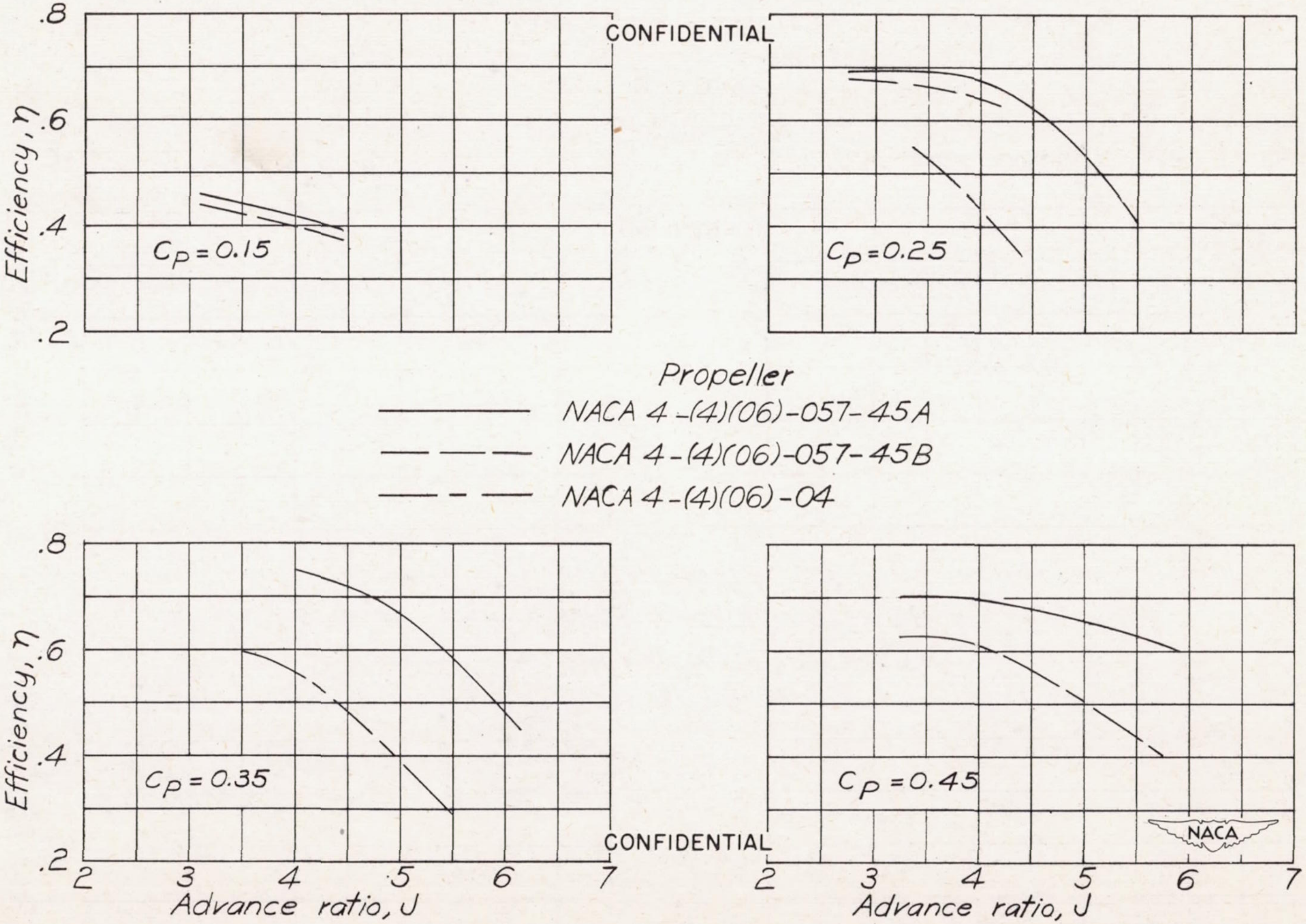
(b) M = 0.70.

Figure 11.– Continued.



(c) M = 0.80.

Figure 11.- Continued.



(d) M = 0.85.

Figure 11.- Concluded.